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CONTENTS

INHERITANCE STUDIES IN WHEAT

X. INHERITANCE OF FIELD REACTION TO RUSTS AND OTHER CHARACTERS

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In some of the earlier series (Pal *et al.*, 1956; Sikka and Rao, 1957; Sikka and Rao, 1958; Suva *et al.*, 1959; Prasad and Rao, 1960), results of studies conducted to find out the mode of inheritance of rust resistance and a number of other characters involving some Indian and exotic wheats have been reported. The mode of inheritance of field resistance to the rusts varied in different varieties and in some cases was influenced by the susceptible parents. These studies were extended to other resistant parents. The results presented in this paper are a continuation of these earlier studies and refer to work on genetics of reaction to black, brown and yellow rusts under field conditions and of a number of other characters, viz., grain shattering, grain colour, glume colour and glume pubescence in crosses involving improved Indian wheats such as N.P. 710, N.P. 718, Pb.C. 591, Pb.C. 281, N.P. 785 and the exotic varieties La Prevision, Frontiera and Kenya 184. P. 2. A.I.F.

MATERIAL AND METHODS

The F_1, F_2 and F_3 generations of the following seven intervarietal crosses of *Triticum aestivum* L. were studied during the crop season of 1957-58. This was also supplemented by the data collected on these crosses during the previous year.

Cross	Characters studied
(1) Pb.C. 281 × Kenya 184. P. 2. A.I.F.	Black rust and grain shattering
(2) N.P. 710 × Kenya 184. P. 2. A.I.F.	Black rust and grain shattering
(3) N.P. 710 × Frontiera	Brown rust and grain shattering
(4) N.P. 710 × La Prevision	Brown rust, yellow rust, grain colour and glume colour
(5) N.P. 710 × N.P. 785	Yellow rust and grain colour
(6) N.P. 718 × N.P. 785	Yellow rust and grain colour
(7) Pb.C. 591 × N.P. 785	Grain colour and glume pubescence

The chief characteristics of the varieties N.P. 710, N.P. 718, Pb.C. 281, Pb.C. 591, Kenya 184. P. 2. A.I.F. and Frontiera have already been given by Sikka and Rao

* At present, Additional Agricultural Commissioner with the Government of India.

(1957). Descriptions of the two remaining varieties, viz., La Prevision and N.P. 785, are given below:

La Prevision (E. 928): This is a variety received from South America. It is a fully bearded variety with glabrous glumes and red grains. It is found to be resistant to brown and yellow rusts in the field. In the seedling stage, it is resistant to races 10, 11, 20, 26, 63, 106, 107 and 108 of brown rust and races 13, 19, 20, 31, A, D, E, F, G and H of yellow rust.

N.P. 785: This variety was evolved at the Indian Agricultural Research Institute from the cross Carsten's V × Pb.C. 518. It is a fully bearded wheat with glabrous white glumes and red grains. It is resistant to all the Indian races of yellow rust both in the adult and seedling stages.

Epiphytotic conditions for testing against all the three rusts were artificially created as described in the earlier series. Nine races and two biotypes of black rust, viz., 15, 21, 24, 34, 40, 42, 75, 117, 194, 15-C and 42-B; eight races of brown rust, viz., 10, 11, 20, 26, 63, 106, 107 and 108; and ten races of yellow rust, viz., 13, 19, 20, 31, A, D, E, F, G and H were released in the field both by spray and dust.

Observations on rusts were recorded on the basis of percentage and nature of pustule. The method followed for recording the rust reactions and other characters was the same as described earlier by Pal *et al.* (1956).

With regard to shattering, all the observations were recorded in the field only. The crop was allowed to stand in the field for a longer time until this character was fully expressed. Plants which showed either complete or partial shattering in their spikes were taken to be susceptible.

EXPERIMENTAL RESULTS

A. *Inheritance of mature plant reaction to rusts*

(i) *Black rust* (*Puccinia graminis tritici* (Erikss and Henn): Two crosses, viz., Pb. C. 281 (S) × Kenya 184. P. 2. A.I.F. (R) and N.P. 710 (S) × Kenya 184. P. 2. A.I.F. (R), were studied for finding out the mode of inheritance of field reaction to black rust. In both Pb.C. 281 and N.P. 710, the intensity of black rust varied from moderate to heavy as compared to Kenya 184. P. 2. A.I.F. which remained completely free. Susceptibility was found to be dominant in both the crosses in F_1. Data on F_2 and F_3 generations are presented in Table I.

From the data presented in Table I, it is seen that field resistance of Kenya 184. P. 2. A.I.F. to black rust is governed by two pairs of duplicate recessive genes.

(ii) *Brown rust* (*Puccinia rubigovera tritici* (Erikss) Carleton): Two crosses, viz., N.P. 710 (S) × Frontiera (R) and N.P. 710(S) × La Prevision (R), were studied against brown rust. The F_1 generation in both the crosses exhibited mesothetic reactions, although majority of the pustules belonged to the susceptible category. Data collected on the F_2 and F_3 generations of these two crosses have been presented in Table II.

TABLE I. MODE OF SEGREGATION OF FIELD REACTION TO BLACK RUST IN F_2 AND F_3 GENERATIONS OF THE CROSSES PB.C. 281 × KENYA 184. P. 2. A.I.F. AND N.P. 710 × KENYA 184. P. 2. A.I.F.

Cross	Generation	Resistant	Heterozygous	Susceptible	Total	X^2	P. value	Mode of segregation
Pb.C. 281 × Kenya 184 P. 2. A.I.F.	F_2	24	..	299	323	0·77	0·50–0·30	15S:1R
	F_3*	5	38	37	80	0·2143	0·90–0·80	1R:8H:7S
N.P. 710 × Kenya 184. P. 2. A.I.F.	F_2	15	..	176	191	0·837	0·50–0·30	15S:1R
	F_3*	5	33	25	63	0·7214	0·70–0·50	1R:8H:7S

* Depicts the number of families, whereas F_2 data pertain to the plant number.

TABLE II. SEGREGATIONS IN THE F_2 AND F_3 GENERATIONS OF THE CROSSES N.P. 710 × FRONTIERA AND N.P. 710 × LA PREVISION FOR FIELD RESISTANCE TO BROWN RUST

Cross	Generation	Resistant	Heterozygous	Susceptible	Total	X^2	P. value	Mode of segregation
N.P. 710 × Frontiera	F_2	66	..	212	278	0·2351	0·70–0·50	3S:1R
	F_3*	22	43	17	82	0·7562	0·70–0·50	1R:2H:1S
N.P. 710 × La Prevision	F_2	14	..	224	238	0·0555	0·90–0·80	15S:1R
	F_3*	7	42	30	79	1·6189	0·50–0·30	1R:8H:7S

* The data relate to the number of families.

The monohybrid segregation of 3S: 1R in the cross N.P. 710 × Frontiera indicates that the resistant Frontiera parent carries one recessive gene pair for field resistance to brown rust. This is confirmed by the data of the 82 F_3 families studied.

Resistance of La Prevision appears to be governed by two recessive gene pairs in cross with N.P. 710.

(iii) *Yellow rust* (*Puccinia glumarum* (*Scbm*) Erikss and Henn): Mode of inheritance of field resistance to yellow rust was studied in three crosses, viz., N.P. 710 (S) × La Prevision (R), N.P. 710 (S) × N.P. 785 (R) and N.P. 718 (S) × N.P. 785 (R). Resistance was found to be dominant in the F_1 generation of all the crosses. Data collected on the F_2 and F_3 generations of these three crosses are presented in Table III.

TABLE III. SEGREGATIONS IN THE F_2 AND F_3 GENERATIONS OF THE CROSSES N.P. 710 × LA PREVISION, N. P. 710 × N. P. 785 AND N. P. 718 × N. P. 785 FOR FIELD RESISTANCE TO YELLOW RUST

Year	Cross	Generation	Resistant	Heterozygous	Susceptible	Total	X^2	P. value	Mode of segregation
1957–58	N.P. 710 × La Prevision	F_2	205	..	57	262	1·5517	0·30–0·20	13R:3S
		F_3*	30	43	6	79	1·1392	0·70–0·50	7R:8H:1S
1956–57	N.P. 710 × N.P. 785	F_2	710	..	155	865	1·0540	0·50–0·30	13R:3S
1957–58		F_2	179	..	40	219	0·0337	0·90–0·80	13R:3S
		F_3*	36	40	4	80	0·2286	0·90–0·80	7R:8H:1S
1956–57	N.P. 718 × N.P. 785	F_2	923	..	224	1,147	1·2292	0·30–0·20	13R:3S
1957–58		F_2	217	..	40	257	1·7137	0·20–0·10	13R:3S
		F_3*	39	35	6	80	1·2821	0·70–0·50	7R:8H:1S

* The data relate to the number of families.

There was a segregation in all the above crosses in the ratio of 13R:3S, indicating the operation of two pairs of genes—one controlling resistance and the other inhibiting the expression of susceptibility. The F_3 data confirm the F_2 findings.

B. *Inheritance of other characters*

In addition to the data collected on the field resistance to different rusts, inheritance of certain other characters such as grain shattering, grain colour, glume colour and glume pubescence was also studied in one or the other of the crosses reported in this paper.

(i) *Inheritance of grain shattering:* Three crosses, viz., Pb.C. 281 (NS) × Kenya 184. P. 2. A.I.F.(S), N.P. 710(NS) × Kenya 184 P. 2. A.I.F.(S) and N.P. 710(NS) × Frontiera (S), were studied to find out the mode of inheritance of grain shattering under field conditions. The F_1 generation in all the three crosses exhibited the shattering character, indicating thereby the dominance of this character. Data collected on the F_2 and F_3 generations of these crosses are presented in Table IV.

From the data presented in the above table it would be observed that the character of shattering is inherited in a simple Mendelian ratio.

(ii) *Inheritance of grain colour:* Four crosses, viz., N.P. 710(W) × La Prevision (R), N.P. 710 (W) × N.P. 785 (R), N.P. 718 (W) × N.P. 785 (R) and Pb.C. 591 (W) × N.P. 785 (R), were studied with regard to the inheritance of grain colour. Red colour of the grain was dominant in F_1 in all the crosses. Data collected from the F_2 and F_3 generations of these crosses are presented in Table V.

From the results tabulated (TableV), it would be seen that N.P. 785 carries one dominant factor for the red grain colour while La Prevision has two such factor pairs.

TABLE IV. INHERITANCE OF GRAIN SHATTERING IN THE F_2 AND F_3 GENERATIONS OF THE CROSSES INVOLVING PB.C. 281, N.P. 710, KENYA 184. P. 2. A.I.F. AND FRONTIERA

Cross	Generation	Shattering	Heterozygous	Non-shattering	Total	X^2	P. value	Mode of segregation
Pb.C. 281 × Kenya 184 P. 2. A.I.F.	F_2	187	..	70	257	0·6861	0·50–0·30	3S:1NS
	F_3*	19	40	21	80	0·10	0·98–0·95	1S:2H:1NS
N.P. 710 × Kenya 184 P. 2. A.I.F.	F_2	110	..	39	149	0·1096	0·80–0·70	3S:1NS
	F_3*	13	35	15	63	0·9048	0·70–0·50	1S:2H:1NS
N.P. 710 × Frontiera	F_2	157	..	60	217	0·8125	0·50–0·30	3S:1NS
	F_3*	21	42	19	82	0·1464	0·95–0·90	1S:2H:1NS

* The data relate to the number of families.

TABLE V. INHERITANCE OF GRAIN COLOUR IN THE F_2 AND F_3 GENERATIONS OF FOUR CROSSES INVOLVING N.P. 710, N.P. 718, PB.C. 591, LA PREVISION AND N.P. 785

Cross	Generation	Red	Heterozygous	White	Total	X^2	P. value	Mode of segregation
N.P. 710 × La Prevision	F_2	181	..	13	194	0·0666	0·80–0·70	15R:1W
	F_3*	36	38	5	79	0·5323	0·80–0·70	7R:8H:1W
N.P. 710 × N.P. 785	F_2	148	..	41	189	1·1023	0·30–0·20	3R:1W
	F_3*	23	45	12	80	4·2750	0·20–0·10	1R:2H:1W
N.P. 718 × N.P. 785	F_2	176	..	53	229	0·4207	0·70–0·50	3R:1W
	F_3*	23	42	15	80	1·8000	0·50–0·30	1R:2H:1W
Pb.C. 591 × N.P. 785	F_2	151	..	53	204	0·0523	0·90–0·80	3R:1W
	F_3*	20	45	15	80	1·8750	0·50–0·30	1R:2H:1W

* The data relate to the number of families.

(iii) *Inheritance of glume colour:* La Prevision had brown glumes and N.P. 710 white ones. Brown colour of the glumes was dominant in the F_1 generation. In the F_2, out of the 194 plants studied, 146 had brown glumes and 48 white glumes. This gave a good fit, with the probability value of 0·95 to 0·90, to a monohybrid ratio of three brown: one white. The F_2 findings were confirmed by the study of 79 F_3 families, where 17 were homozygous for brown, 21 for white, while 41 segregated in the ratio of three brown: one white. The character thus appears to be simply inherited.

(iv) *Inheritance of glume pubescence:* This character was studied in the cross Pb.C. 591 (P) × N.P. 785 (G). Glume pubescence was dominant followed by a monohybrid

segregation ratio of three pubescent: one glabrous in the F_2 generation. Thus, 148 plants out of a population of 204 were pubescent while 56 were glabrous. This was further confirmed in the F_3 generation, where out of a total number of 80 families 17 bred pure for pubescence, 19 to glabrousness, while 44 were heterozygous. This gave a good fit for one P: two H: one G ratio, with a probability value of 0·70 to 0·50.

C. *Association between different characters*

All the data of the six crosses studied against rusts were statistically analysed with a view to ascertaining the linkage relationships between the field reaction to rusts on the one hand, and grain shattering, grain colour, glume colour and glume pubescence on the other. The results of the analysis based on F_2 segregations are summarised in Table VI.

From the data presented in Table VI, there appears to be no linkage between the different characters studied. In the case of the cross N.P. 710 × La Prevision, there is evidence to show some linkage between the brown and yellow rusts for one degree of freedom, while there is no such evidence for three degrees of freedom when calculated with the contingency method. Besides, the F_3 data did not reveal any association between these characters. It may, therefore, be inferred that the incidence of brown rust in this cross was inherited independently of yellow rust.

DISCUSSION

The mode of inheritance of field resistance to black rust in crosses of Kenya 184, P. 2. A.I.F. (resistant) with Pb.C. 281 and N.P. 710 (susceptible) indicated the operation of two recessive factor pairs determining resistance to this rust in the Kenya wheat. These results can be explained by assuming that the susceptible varieties Pb.C. 281 and N.P. 710 carry two pairs of dominant genes for susceptibility, viz., $S_1 S_1 S_2 S_2$ and Kenya 184 P. 2. A.I.F., the corresponding recessive alleles $s_1\ s_1\ s_2\ s_2$. Clark (1924) obtained a similar segregation ratio of 15 susceptible : 1 resistant for field resistance in the cross Kota (R) × Hard Federation (S). Clark and Smith (1928) working with the *durum* cross Nodak (R) × Kahla (S) observed the F_1 to be susceptible followed by a segregation ratio of 15S : 1R in the F_2. Hayes *et al.* (1925, 1936) in the double cross (Marquis × Iumillo) × (Marquis × Kanred), from which Thatcher was evolved, recorded similar dihybrid segregations. Similar dihybrid ratios of 15S : 1R were also reported by Churchward (1938) in the cross Federation (S) × Hope (R), by Murty and Lakhani (1958) in the crosses Gaza (R) × N.P. 710 (S) and Gaza (R) × N.P. 718 (S).

Field resistance to brown rust in the cross N.P. 710 (S) × Frontiera (R) appeared to be governed by a single pair of recessive factors, while in the cross N.P. 710 (S) × La Prevision (R), evidence of the operation of two pairs of recessive genes was obtained. It appears that N.P. 710 differs from Frontiera by a single gene pair and from La Prevision by two pairs. When it is assumed that duplicate genes are involved in controlling field resistance, it is difficult to explain the behaviour of N.P. 710 in these two crosses. It might be that the systems present in Frontiera and La

TABLE VI. CHI-SQUARE TEST FOR ASSOCIATION BETWEEN FIELD REACTION TO RUSTS AND OTHER CHARACTERS IN THE F_2 GENERATIONS OF DIFFERENT CROSSES

Year	Cross	Characters studied	Mode of segregation	F_2 observed				Total	X^2	P. value
				Susceptible shattering	Susceptible non-shattering	Resistant shattering	Resistant non-shattering			
1957–58	Pb.C. 281 × Kenya 184 P.2. A.I.F.	Black rust and shattering	45:15:3:1	177	58	11	8	254	3·43	0·10–0·05
	N.P. 710 × Kenya 184 P.2. A.I.F.	do.	do.	99	34	8	4	145	0·50	0·50–0·30
	N.P. 710 × Frontiera	Brown rust and shattering	9:3:3:1	142	51	13	10	216	0·82	0·50–0·30
				Susc. brown Res. yellow	Susc. brown Susc. yellow	Res. brown Res. yellow	Res. brown Susc. yellow			
	N.P. 710 × La Prevision	Brown rust and yellow rust	195:45:13:3	169	52	15	0	236	5·16* 7·37†	0·05–0·02 0·10–0·05
				Susc. red	Susc. white	Res. red	Res. white			
	do.	Brown rust and grain colour	225:15:15:1	145	11	24	3	183	2·11	0·20–0·10
				Susc. brown	Susc. white	Res. brown	Res. white			
	do.	Brown rust and glume colour	45:15:3:1	123	40	17	9	189	2·75	0·10–0·05
				Res. brown	Res. white	Susc. brown	Susc. white			
	do.	Yellow rust and glume colour	39:13:9:3	112	41	32	9	194	0·42	0·70–0·50
				Res. red	Susc. red	Res. white	Susc. white			
	do.	Yellow rust and grain colour	195:45:13:3	143	38	10	3	194	0·04	0·90–0·80
				Res. red	Res. white	Susc. red	Susc. white			
	N.P. 710 × N.P. 785	do.	39:13:9:3	119	32	28	9	188	0·14	0·80–0·70
	N.P. 718 × N.P. 785	do.	do.	152	45	24	8	229	0·10	0·80–0·70

* Analysis with Chi-square linkage showed indications of some linkage in F_2 though the F_3 results did not confirm it.
† Analysis with Chi-square contingency did not show any linkage.

Prevision are different. This needs further critical study in a cross between Frontiera and La Prevision. A number of workers including Vohl (1938), Wu (1950), Wu and Ausemus (1953), Murty and Lakhani (1958) reported the inheritance of field resistance to brown rust based on a single and double recessive gene pair or pairs. Field resistance of Frontiera to brown rust was also reported by Suva *et al.* (1958) to be governed by a single recessive gene pair in the cross Pb.C. 591 (S) × Frontiera (R).

In all the three crosses studied against yellow rust in the field, viz., N.P. 710(S) × La Prevision(R), N.P. 710 × N.P. 785(R) and N.P. 718(S) × N.P. 785(R), a segregation ratio of 13 resistant : three susceptible was observed. The results indicate that both the resistant varieties, viz., La Prevision and N.P. 785, carry one basic recessive gene pair for field resistance to yellow rust (s s), in addition to a pair of inhibitory genes (I I) which suppresses susceptibility. The susceptible varieties N.P. 710 and N.P. 718 carried their alleles, viz., S S i i. On this assumption, genetypes SI, s I and s i would be resistant while S i would be susceptible. The F_2 findings are further confirmed by the F_3 observations. Working with ten races of yellow rust under field conditions, Pal *et al.* (1956) reported dominance of field resistance to yellow rust in the cross N.P. 789(S) X Frondoso (R) governed by three factor pairs. However, Suva *et al.* (1958), in the crosses Pb.C. 281(S) × Cometa Klein (R) and N.P. 718(S) × Cometa Klein (R), found dominance of resistance to yellow rust governed by a single gene pair.

The grain shattering character of Kenya 184. P. 2. A.I.F. and Frontiera in crosses with N.P. 710 or Pb.C. 281 was dominant and inherited monogenically. However, the technique here employed is far from perfect. Only, advantage was taken of the hot dry westerly winds which induced shattering. Unifactorial mode of inheritance of shattering has been reported by Lewicki (1928). The inheritance of shattering in wheat has been recently reviewed by Porter (1959).

The red grain colour of N.P. 785 was governed by a single dominant gene and that of La Prevision by a pair of duplicate genes. The work of Sikka and Rao (1957) and Suva *et al.* (1958) showed the number of genetic factors controlling the red grain colour of Frontiera to be three, while in Kenya 184. P. 2. A.I.F. two pairs, in N.P. 790 one pair and in Cometa Klein two pairs were involved.

The inheritance of glume colour in the cross N.P. 710 (white) × La Prevision (brown) was governed by a single dominant factor. Ayad (1952) had explained the inheritance of brown glume colour as due to two factor pairs and Sears (1948) as due to three major factors. But in the present cross, only a single factor seemed to govern the inheritance of this character. These results were similar to those obtained by Howard and Howard (1912 and 1915), Pal *et al.* (1956), Sikka and Rao (1957), and Suva *et al.* (1958).

The glume pubescence of Pb.C. 591 in cross with N.P. 785 was inherited as a single dominant factor. Similar results have been reported by many workers including Spillman (1902), Kadam (1936), Sen and Joshi (1955), Pal *et al.* (1956) and Sikka and Rao (1957).

The studies on association between different characters summarised in this paper have not shown any linkage between rusts and other characters. Similarly, there appeared to be no linkage between field resistance to brown rust and yellow rust.

Aamodt (1922 and 1923) followed by a large number of workers also found independent inheritance of rusts and some of the morphological characters studied by them. Recently, Sen and Joshi (1955) and Suva *et al.* (1958) also reported similar results.

SUMMARY

The mode of inheritance of field reaction to black, brown and yellow rusts and a number of other characters was studied in crosses involving Kenya 184. P. 2. A.I.F., Frontiera, La Prevision, N.P. 785, N.P. 710, N.P. 718, Pb.C. 281 and Pb.C. 591.

The field resistance of Kenya 184. P. 2. A.I.F. to black rust was observed to be governed by two pairs of recessive genes.

The field resistance of Frontiera and La Prevision to brown rust indicated the operation of one and two recessive gene pairs, respectively.

The field resistance of La Prevision and N.P. 785 to yellow rust was seen to be controlled by two factor pairs. One recessive factor pair was directly responsible in governing field resistance while the other inhibitory factor suppressed the expression of susceptibility.

The grain shattering character of Kenya 184. P. 2. A.I.F. and Frontiera was observed to be governed by a single dominant gene.

N.P. 785 was observed to carry a single dominant gene for red grain colour while La Prevision carried two genes.

The glume colour of La Prevision and glume pubescence of Pb.C. 591 were found to be monogenically inherited.

The field resistance to rusts and other characters studied were all observed to be inherited independent of each other.

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REFERENCES

Aamodt, O. S. 1922. The inheritance of resistance to several biological forms of *Puccinia graminis tritici* in a cross between Kanred and Marquis wheats. *Phytopath.* **12**: 32 (Abst.).

——— 1923. The inheritance of growth habit and resistance to stem rust in a cross between two varieties of common wheat. *J. Agric. Res.* **24**: 457-69.

Ayad, M. A. G. 1952. Inheritance studies of some qualitative and quantitative character in Egyptian varieties of wheat. *Proc. Egypt Acad. Sci.* **8**: 26-38.

Churchward, J. C. 1938. Studies on physiologic specialization of the organism causing bunt in wheat and genetics of resistance to this and certain other wheat diseases. Part II. Genet. Studies. *J. Proc. roy. Soc. N.S.W.* **71**.

Clark, J. A. 1924. Segregation and co-related inheritance in cross between Kota and Hard Federation wheat for rust and drought resistance. *J. agric. Res.* **29**: 1-49.

——— and Smith, R. W. 1928. Inheritance in Nodak and Kahla *durum* wheat crosses for rust resistance, yield and quality at Dikinson, North Dakota. *J. Amer. Soc. Agron.* **20**(12): 1297-1304.

Howard, A. and Howard, G. L. C. 1912. On the inheritance of some character in wheat I. *Mem. Dept. Agric. India Bot. Ser.* **5**: 1-47.

HOWARD, A. and HOWARD, G. L. C. 1915. On the inheritance of some characters in wheat II. *ibid.* **7**: 273-85.

KADAM, B. S. 1936. Genetics of the Bansi wheat of Bombay Deccan and synthetic Khapli. Part I. *Proc. Indian Acad. Sci. Sect. B.* **4**: 357-69.

LEWICKI, S. 1928. Shedding of kernels as a heritable character in wheat (in Polish). *Mem. Inst. Natl. Polon. Econ. Rurale Pulawy* **9**: 19-31 (1928). (*Abst. U.S.D.A. Exp. Sta. Rec.* **61**: 226, 1929).

MURTY, G. S. and LAKHANI, L. B. 1958. Genetic studies in crosses between *aestivum* varieties and the *durum* wheat, Gaza. *Indian J. Genet. Pl. Breed.* **18**(2): 163-77.

PAL, B. P., SIKKA, S. M. and RAO, M. V. 1956. Inheritance studies in wheat. *ibid.* **16**(1): 32-46.

PORTER, KENNETH B. 1959. The inheritance of shattering in wheat. *Agron. J.* **51**(3): 173-77.

PRASAD, R. B. 1959. Studies on the inheritance of field reaction to rusts and certain other characters in some intervarietal crosses of *Triticum aestivum* L. *Assoc. thesis I.A.R.I.* (1959—unpublished).

SEARS, E. R. 1948. The cytology and genetics of the wheats and their relatives. *Adv. Genet.* **2**: 239-70.

SEN, S. and JOSHI, M. G. 1955. Inheritance of resistance to black rust in wheat. *Indian J. Genet. Pl. Breed.* **15**(1): 36-46.

SIKKA, S. M. and RAO, M. V. 1957. Inheritance studies in wheat. II. *ibid.* **17**(1): 7-18.

——— and ——— 1958. Inheritance studies in wheat. III. Inheritance of field reaction to black rust. *ibid.* **18**(1): 34-40.

SPILLMAN, W. J. 1902. Quantitative studies on the transmission of parental characters to hybrid offspring. *U.S.D.A. Expt. Sta. Bull.* **115**: 88-98.

SUVA GHOSH, SIKKA, S. M. and RAO, M. V. 1958. Inheritance studies in wheat. IV. Inheritance of rust resistance and other characters. *Indian J. Genet. Pl. Breed.* **18**(2): 142-62.

SWENSON, S. P., BUCHHOLTZ, W. F. and GRAFIUS, J. E. 1947. Complementary genes for leaf rust resistance and the inheritance of stem rust resistance and the awnedness in a spring wheat cross. *J. Amer. Soc. Agron.* **39**: 739-49.

VOHL, G. J. 1938. Investigations on brown rust of wheat, *P. triticina* (Erikss). *Z. Zucht., A.* **22**: 233-70.

WU, C. S. 1950. Inheritance of leaf rust reaction and other characters in a spring wheat cross. *Ph.D. Thesis, Univ. Minnesota,* (1950).

——— and AUSEMUS, E. R. 1953. Inheritance of leaf rust reaction and other characters in spring wheat cross. *Agron. J.* **45**: 43-48.

QUANTITATIVE STUDIES ON STEM DEVELOPMENT IN RICE (*ORYZA SATIVA* L.)

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Plant physiologists, morphologists and geneticists perennially are confronted with the problem of asssessing stages of development of grass shoots. A number of conventionally employed indices of developmental stages in grasses include (1) fresh or dry weight of shoot system or whole plant, (2) shoot height, (3) leaf number, and here, usually number of exposed leaves, (4) age of plant from date of seeding, (5) gross morphologic stages, e.g., seedling, tillering, "jointing", "boot", and "head emergence" stages. A number of investigators (Andersen, 1952 and 1954; Bonnett, 1935, 1936, 1937, 1940 and 1953; Evans and Grover, 1940) have adopted a method in which numbers or stage indices are arbitrarily assigned to successive morphologic stages of vegetative and reproductive shoots. The number of primordial leaf protuberances and the stages of development of entire inflorescences, of spikelets, and of florets and their parts constitute the primary basis for this system. By this method one may assess stages of shoot development independently of time in a qualitative manner. In addition, such data are invaluable in quantitative studies of shoot development in grasses.

Researches of Prat (1935), Anderson and Schregardus (1944), Johnson (1954), Nilson *et al.* (1957) and Palmer (1958) directly come to grips with the problem of expression of developmental stages in grass stems. Prat's studies (1935) reveal progressive basipetal development of the intercalary meristem in elongating leaves and the internodes associated with these leaves. This pattern has been correlated with time, duration and amount of elongation in the stem and leaf. Anderson and Schregardus (1944) have presented data on lengths of successive internodes of *Tripsacum*, which reveal differences in rate and amount of internodal elongation for two species of this genus. Johnson (1954) has presented similar data for several varieties of *Triticum vulgare*. More recently, Nilson *et al.* (1957) extended the investigations on *Triticum* by comparing internode lengths and plant (shoot) height with cell length of epidermal and peripheral ground parenchyma ("cortical") cells of internodes of eight varieties. Their data show an inverse relationship between internode length and length of ground parenchyma cells and a similar but less consistent relationship with epidermal cells. Recently, Palmer (1958) has presented correlative data on internode, leaf, rhizome, axillary bud, and tiller (lateral shoot) lengths of *Agropyron repens* at different stages of development and in connection with effect of photoperiod and light intensity on rhizome growth.

The present paper is a report on a quantitative analysis of gross stages of stem development in rice shoots. The study constitutes part of a morphogenetic inquiry into the mechanism of stem elongation in grasses.

MATERIAL AND METHODS

Culture techniques: Rice variety Century Patna 231 was planted in October, 1958. Seed was sown in a layer of vermiculite (ca. 2 cm. depth) in round plastic containers, 13·5 cm. in diameter, 13·2 cm. in height, 1500 ml. volume (Fig. 1). Cultures were maintained in a greenhouse cubicle with a temperature regime of 21° to 24° C, watered to maintain a flooded condition one to two cm. above vermiculite after seedling stage and fertilized every two weeks with IM $(NH_4)_2 CO_3$ diluted at 100 ml. of IM stock per gallon tap water, which was used at a rate of 100 ml. per culture[1].

FIG. 1. RICE CULTURES EMPLOYED IN QUANTITATIVE ANALYSIS OF STEM DEVELOPMENT, ILLUSTRATED AT AN EARLY STAGE OF SHOOT DEVELOPMENT OF RICE PLANTS. FOR CULTURE METHODS SEE TEXT. X 1/10.

[1]Currently, I am using ca. 2·5 gm. Amberlite IRC 50(NH_4) resin per culture, applied two weeks after planting. This meets nitrogen requirements for these seedlings for about five weeks. Then I use $(NH_4)_2 CO_3$ as specified above. The resin releases NH_4^+gradually and does not provide as large a pool of NH_4^+as $(NH_4)_2 CO_3$ at the time of application. I have found that rice seedlings grown in the greenhouse during periods of lowlight intensity and short photoperiods of winter months become chlorotic and may die. $(NH_4)_2 CO_3$ fertilization accentuates this condition, whilst NH_4 resin prevents it.

All depauperate plants were removed from cultures during seedling phase of development. Plants of relatively uniform size were obtained by overseeding and thinning 20 days later to desired number (10 plants). This density of plants was sufficient to obviate the complicating factor of lateral shoot development.

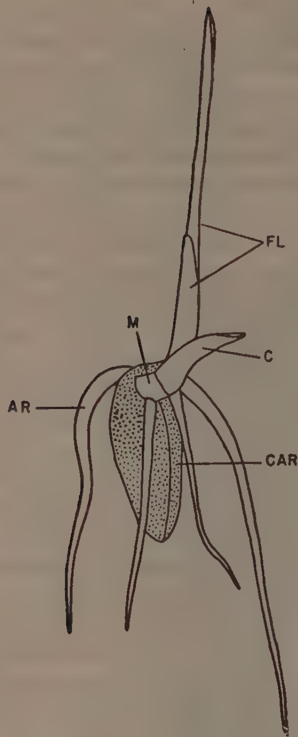
Analytical techniques: Cultures were sampled approximately every seven days (longer intervals at later stages of shoot development) from seed stage to time of maturation of the inflorescence. Twenty plants constituted each sample. These were removed at random from the cultures.

Initially, roots were excised from each plant. It was essential to cut the roots as close to the shoot base as possible to make any error in fresh and dry weight determinations from this source negligible. The analysis of shoots then proceeded as follows: (1) shoots were cut with single-edge razor blade in approximately median longitudinal plane perpendicular to the planes of the leaf blades to expose all definitive nodes, internodes and sheath bases of the shoot axis; (2) number of definitive nodes was recorded with the aid of the dissecting microscope; (3) lengths of successive internodes, from the coleoptilar node to the first discernible nodal plate below the shoot apex, were recorded, again using the dissecting microscope; (4) in conjunction with the last step, length of the inflorescence was obtained where it was present; (5) the shoot of each plant was finally separated into sheath, lamina (or whole leaves with seedlings), stem and inflorescence (if present) fractions by appropriate cutting and dissection; (6) these fractions, representing the combined sample of 20 plants, were blotted and weighed, dried to a constant weight at 100° C and reweighed.

The methods of measurement of internode and stem lengths and assessment of number of definitive nodes at different stages of observation are illustrated in Figs. 2 and 3. For the seedling represented in Fig. 2 the stem length would be zero in view of the absence of any definitive nodes above the coleoptilar node. The mesocotyl was not included in stem measurements because this structure, the seed and the seminal roots gradually disintegrate and slough-off from vegetative shoots. Also, there is some doubt as to whether the mesocotyl is morphologically stem-like in structure (Brown, 1959).

In this study successive stages are expressed according to plastochron numbers, which correspond to the number of *definitive nodes* observed at successive dates of observation. Definitive nodes are here defined as those nodes that are clearly delimited in longitudinal median sections of living rice shoots as observed with the dissecting microscope.

The portion of the shoot in Fig. 4 is drawn from a vegetative plant approaching transition to reproductive stage of development. The plastochron number for this shoot is 10, obtained directly by counting the number of definitive nodes, including the coleoptilar node. The stem length is obtained by measuring the distance between the coleoptilar node and the shoot apex. Internode lengths are measured between successive nodal plates (here acropetally or towards the shoot apex). A similar procedure is employed for shoots in reproductive phase of development (Fig. 4-6). In this study, the uppermost node was considered as the node between the inflorescence base and the uppermost internode or peduncle; the peduncle here was designated the uppermost internode of the long internode system.



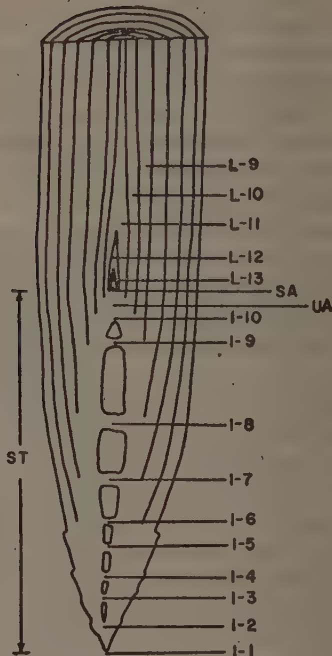


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Fig. 2. Drawing of rice seedling (9 days old) as grown in Petri dish culture under sterile conditions. Adventitious roots (AR), caryopsis or grain (CAR), mesocotyl (M), coleoptile (C) and two foliage leaves (FL) are depicted. Ca. X 6.

Fig. 3. Drawing from vegetative rice shoot (106 days old) in median longitudinal plane. It illustrates successive definitive nodal plates (I-1 to I-10); undifferentiated axis (UA), where no definitive nodes are in evidence; the position of the shoot apex (SA); leaves associated with nodes 9 and 10 (L-9 and L-10); and young leaves whose leaf bases are associated with the undifferentiated axis (L-11 to L-13). ST, stem portion of shoot. Ca. X 4.

GROSS MORPHOLOGY OF THE RICE SHOOT

For a clearer understanding of the analyses of shoot development, it is first necessary to describe briefly the gross morphology of the rice shoot. Cytohistologic data on structure and development of the rice stem are presented in the papers of Juliano and aldama (1936), Majumdar and Saha (1956), and Kaufman (1959).

In the rice variety Century Patna 231, as grown under the environmental regime cited earlier, the stem consists of four to eight superposed and greatly telescoped basal internodes (Fig. 4-6). These have their inception during vegetative phase of shoot

development. Five to six new internodes and nodes (Figs. 4-6) were initiated just before and during transition to reproductive phase. These internodes, in contrast with the basal ones, elongated appreciably; they became the internodes that comprise the greatest part of the total stem system in terms of length and dry weight.

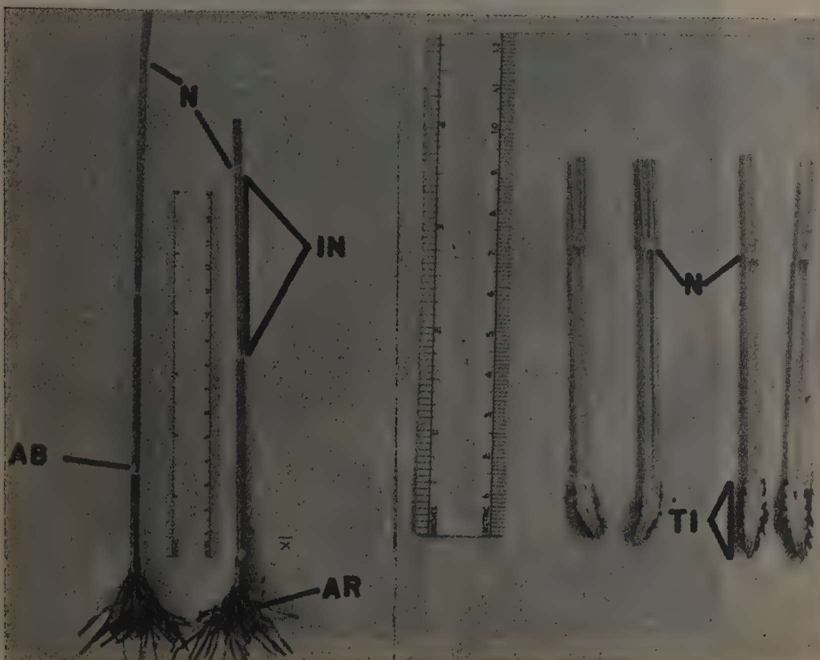

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FIG. 4. EXTERNAL MORPHOLOGIC FEATURES OF STEMS OF NON-IRRADIATED (LEFT) AND IRRADIATED (RIGHT) SHOOTS OF THE CP-231 VARIETY OF RICE. UPPER INTERNODES AND INFLORESCENCES HAVE BEEN REMOVED. LEAVES HAVE BEEN EXCISED TO REVEAL AXILLARY BUD (AB), NODES (N), LONG UPPER INTERNODES (ONE IS MARKED IN). ADVENTITIOUS ROOTS (AR) ARE ILLUSTRATED AT BASAL PART OF EACH SHOOT. X 1/5.

FIG. 5. MEDIAN LONGITUDINAL VIEW OF SHOOT BASES AND PART OF LONG INTERNODE SYSTEMS OF SHOOTS OF TWO RICE PLANTS. UPPERMOST OF LONG INTERNODES, INFLORESCENCES, AND MOST OF LEAVES HAVE BEEN REMOVED. N, NODE; TI, TELESCOPED BASAL INTERNODES. X 1/4.

Several morphologic features of the mature rice shoot are illustrated in Figs. 5 and 6. The axillary buds are inserted at the nodes in an alternate and distichous arrangement. The adventitious roots primarily are associated with the basal telescoped node-internode system. The inflorescence is enclosed in the last formed leaf and is attached to the peduncle, the longest and uppermost internode of the extended internode system.

FIG. 6. TWO RICE SHOOTS IN REPRODUCTIVE STAGE OF DEVELOPMENT. SHOOT AT LEFT WAS CUT IN MEDIAN LONGITUDINAL PLANE. LEAVES, EXCEPT LAST-FORMED LEAF SURROUNDING INFLORESCENCE, WERE EXCISED TO REVEAL GROSS INTERNAL FEATURES OF UPPER INTERNODES (UI). THE TRANSVERSE LIGHT REGIONS IN THE INTERNODES OF SHOOT AT LEFT REPRESENT REMNANTS OF CENTRAL GROUND PARENCHYMA TISSUE AFTER FORMATION OF THE CENTRAL LACUNAE. SHOOT AT RIGHT HAD ALL BUT LAST LEAF EXCISED TO ILLUSTRATE EXTERNAL GROSS MORPHOLOGY OF UPPER NODES AND INTERNODES OF THE SHOOT. P, PANICLE (INFLORESCENCE); BI, TELESCOPED BASAL INTERNODES; AR, ADVENTITIOUS ROOTS. X 1/7.

RESULTS OF ANALYSES OF SHOOT DEVELOPMENT

(i) *The plastochron concept as applied to stems of the rice plant:* In order to express stem development in rice on a quantitative basis, that is correlated directly with morphologic development of the shoot (irrespective of chronologic time), the concept of plastochron number was employed. As applied to stem development in rice, it is here specifically defined as the *mean number of definitive nodes* in a sample of shoots in a population at any morphologic stage of development (cf. p. 5 for definition of *definitive node*).

The use of the plastochron number concept, as defined above, is based on the following premises:

(1) A genetically pure-line stock of the Century Patna 231 variety of *Oryza sativa* constitutes the experimental plant used in these studies and in the application of the plastochron number concept. Extension of the concept to other varieties of rice and to other grasses must await further investigation.

(2) The standard deviation of the mean number of definitive nodes in shoots sampled at successive stages of development (Table I) does not show increasingly significant variance, whilst the converse is true for stem length (Table II).

(3) The mean number of definitive nodes provides a more reliable basis for assigning plastochron numbers than mean leaf number; it is difficult to obtain accurate counts of young leaves and leaf primordia using large numbers of living shoots. This parameter is also more reliable than mean number of internodes since nodal plates (definitive nodes) are more easily observed and more accurately counted (Fig. 6).

(ii) *Number of definitive nodes:* This parameter of shoot growth was investigated from seedling phase to reproductive phase at 19 successive observation periods. The method of identifying and recording numbers of definitive nodes is described under Analytical Techniques.

TABLE I. MEAN NUMBER OF DEFINITIVE NODES IN MAIN AXES OF RICE SHOOTS (VARIETY CENTURY PATNA 231) AT DIFFERENT STAGES OF DEVELOPMENT

Stage of shoot development	Age of plants (days)	Collection number[1]	Mean number of definitive nodes	Standard error of the mean[2]
Vegetative (seed)	0	1	0	..
Vegetative (seedling)	7	2	1·00	..
	13	3	2·00	..
Vegetative (formation of basal internode system)	20	4	3·00	..
	27	5	3·20	0·08
	52	7	5·61	0·18
	56	8	6·52	0·13
	70	9	7·26	0·15
	77	10	7·40	0·11
Transition to reproductive (cessation of leaf initiation)	84	11	7·68	0·13
	91	12	8·53	0·12
Reproductive (grand phase of shoot elongation)	98	13	10·21	0·18
	105	14	10·40	0·13
	112	15	11·00	0·15
	119	16	11·10	0·14
	128	17	11·65	0·11
	142	18	11·60	0·20
Reproductive (completion of stem elongation)	177	19	12·80	0·25

[1] Sample size = 20 plants for each collection.

[2] No deviation from means occurred in samples of collection numbers 2 to 4.

The mean value for the total number of definitive nodes in main axes of shoots collected in the late reproductive phase (collection 19) was 12·08 ± 0·24 (Table I). The total number of nodes and frequency of occurrence of different numbers of nodes in the long and short internode systems of shoots observed at this stage are depicted in Fig. 7. The most frequent number of definitive nodes in the short internode system is eight, but the spread in node number values is relatively large. In contrast, the most frequent number of definitive nodes in the long internode system is six with much lower frequency of occurrence of node numbers above and below this value. The data, therefore, suggest that the number of definitive nodes in the long internode system approaches a more constant value than that obtained for the short internode system in the mature shoots that were investigated. The same would also hold true for number of internodes in both portions of the stem.

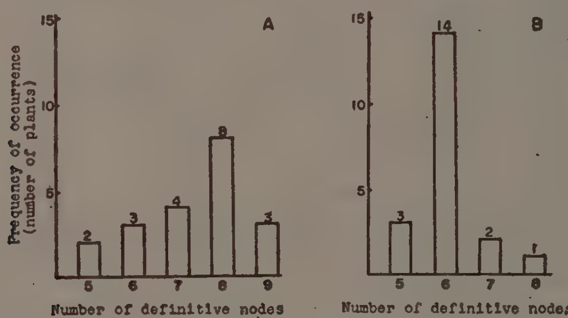

FIG. 7. FREQUENCY DISTRIBUTION OF NODE NUMBERS IN SHORT (A) AND LONG (B) INTERNODE SYSTEMS OF RICE SHOOTS (VARIETY CENTURY PATNA 231) OBTAINED IN LATE REPRODUCTIVE PHASE. SAMPLE SIZE WAS 20. PLANTS WERE OBTAINED FROM COLLECTION 19 (177 DAYS AFTER PLANTING SEED). MEAN NUMBER OF DEFINITIVE NODES WAS 12·8±0·05.

Data in Table I reveal that standard error values for mean number of definitive nodes at successive stages of shoot development are not significantly large. However, there is evident a tendency for the standard error values to increase silghtly at the last two observation periods; this is also reflected by the increased confidence limits values (five per cent level) for these collections (Fig. 8). It is of interest to contrast these values with the standard error and confidence limits values for mean stem lengths at successive stages of shoot development (Table II and Fig. 9); the mean node number varies to a lesser extent than mean stem length. This was the primary reason for basing plastochron number on mean number of definitive nodes (cf. Analytical Techniques section).

During the seedling phase of shoot development, formation and separation of nodal plates above the coleoptilar node was only first evident when plants were thirteen days old (plastochron 2). Based on observations of paraffin embedded material (eight μ thick) and living sections of seedling shoots (collections two to five), initial appearance of definitive nodal plates was not observed until plastochron 2 for the

following reasons: (a) slow rate of thickening of seedling shoot bases; (b) less total internodal elongation with consequent smaller degree of separation of leaf insertion regions associated with nodal plates in the short internode system; (c) lack of formation of internodal lacunae is one to two of the most basal internodes; and (d) relatively late time of initiation and development of internodal lacunae in seedling internodes where such lacunae form.

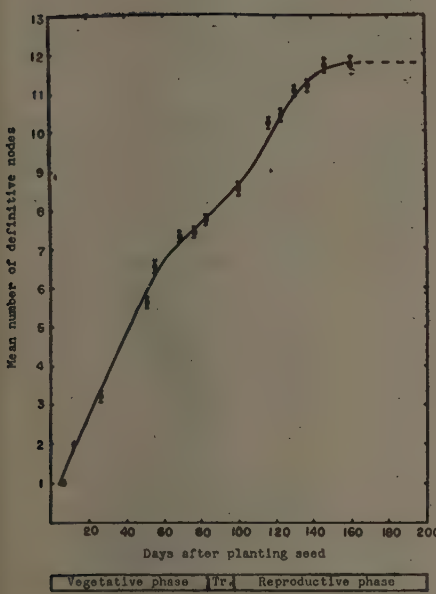

FIG. 8. MEAN NUMBER OF DEFINITIVE NODES OF RICE SHOOTS (VARIETY CENTURY PATNA 231) OBTAINED FROM SEEDLING TO LATE REPRODUCTIVE STAGES OF DEVELOPMENT. CONFIDENCE LIMITS (5 PER CENT LEVEL) ARE INDICATED BY VERTICAL LINE AT EACH POINT. *Tr.*=TRANSITION TO REPRODUCTIVE PHASE.

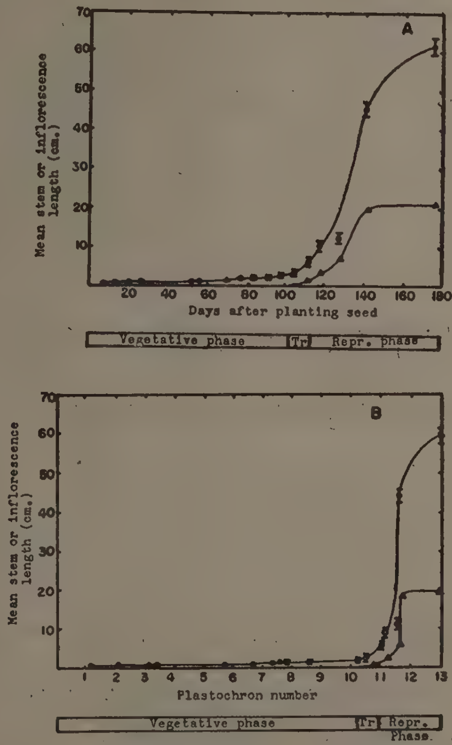

FIG. 9. MEAN STEM (-o-) AND INFLORESCENCE (-Δ-) LENGTHS OF RICE SHOOTS (VARIETY CENTURY PATNA 231) AT SEVERAL STAGES OF DEVELOPMENT, PLOTTED AS A FUNCTION OF CHRONOLOGIC TIME (A) AND PLASTOCHRON NUMBER (B). PLASTOCHRON NUMBER VALUES ARE EQUIVALENT TO NUMBER OF DEFINITIVE NODE VALUES. SAMPLE SIZE PER COLLECTION WAS 20 PLANTS. CONFIDENCE LIMITS (5 PER CENT LEVEL) ARE INDICATED BY VERTICAL LINE AT EACH POINT. *Tr.*=TRANSITION TO REPRODUCTIVE PHASE.

In the reproductive phase (plastochrons 10·21 to 12·80), the rate of appearance of definitive nodes diminishes significantly (Fig. 8). The basis for this is that the last formed nodes are initiated just prior to and during transition to the reproductive phase

TABLE II. MEAN LENGTH OF STEMS OF MAIN AXES OF RICE SHOOTS (VARIETY CENTURY PATNA 231) AT DIFFERENT STAGES OF DEVELOPMENT

Stage of shoot development	Plastochron number	Collection number*	Mean length of stem (cm.)	Standard error of the mean
Vegetative (seed)	0	1	0·0†	..
Vegetative (seedling)	1·0	2	0·0†	..
	1·0	3	0·0†	..
Vegetative (formation of basal internode system)	2·0	4	0·17	0·01
	3·2	5	0·27	0·01
	5·6	7	0·57	0·01
	6·2	8	0·74	0·02
	7·3	9	0·99	0·03
	7·4	10	1·19	0·04
Transition to reproductive (cessation of leaf initiation)	7·7	11	1·28	0·06
	8·5	12	1·65	0·14
Reproductive (grand phase of shoot elongation)	10·2	13	1·87	0·10
	10·4	14	2·41	0·26
	11·0	15	5·33	0·69
	11·1	16	9·51	0·80
	11·3	17	11·26	0·99
	11·6	18	44·30	1·24
Reproductive (completion of stem elongation)	12·8	19	60·78	1·84

* Sample size = 20 plants for each collection.
† Zero values because no definitive nodes occurred above the coleoptilar node; hence, stem lengths were zero by the measurement system employed in this study.

of shoot development. In successive samples of the population studied, in which samples were obtained after transition to reproductive phase, the number of plants in which internodal elongation and subsequent delimitation of discrete nodal plates occurred, increased gradually (based on measurements of internode lengths, the mean values of which appear in Table III).

(iii) *Mean stem length:* Mean stem length increases subtly and only slightly during vegetative phase of shoot development (Table II, Fig. 9). This is a reflection of the formation of the short internode system during this period (cf. Table III). The dominant morphogenetic activity during plastochrons 1 to 10 (vegetative phase) is leaf initiation and development. The leaves elongate perceptibly, whilst the internodes associated with these leaves do not elongate appreciably, especially when

contrasted with the longer internodes formed later. This type of development of the stem during most of the vegetative phase of shoot development results in the formation of the short internode system with its telescoped nodal plates.

The rate of stem elongation begins to increase slightly and at a gradual rate just prior to transition to the reproductive phase. This trend persists through the transition phase (Fig. 9); this is significant because it suggests that the initiation and early development of the reproductive shoot apex do not influence the rate of stem elongation in the axis below the apex. However, with cessation of leaf initiation, and after transition to reproductive phase, a profound shift in shoot morphogenesis occurs; namely, a change from leaf initiation and elongation to stem and inflorescence elongation.

The grand phase of stem elongation is initiated after transition to reproductive phase. In the variety studied the stem length increased from 2·41 to 66·78 cm. during this phase of stem development. It persisted for ca. twenty-five days (Fig. 9A) or, in other terms, ca. 1·8 plastochrons (Fig. 9B). The grand phase of inflorescence elongation followed that of stem elongation by about 0·4 plastochrons (ca. 10 days). This is explained by the fact that elongation in the long internode system, together with the inflorescence, is initiated first in the most basal of the long internodes and proceeds acropetally; the last of the long internodes to elongate is the inflorescence peduncle. The salient feature to be emphasized here is that the grand phase of stem elongation *precedes* initiation and early development of the inflorescence; and it is of relatively short duration in the total time or number of plastochrons represented in the development of the main axis of the shoot.

Values for standard error of mean stem lengths (Table II) are relatively similar and at a low level of variance for plastochrons 2·0 ($0{\cdot}17 \pm 0{\cdot}01$) to 7·7 ($1{\cdot}28 \pm 0{\cdot}06$). From plastochrons 8·5 to 12·8 the standard error values, with some deviations, increase gradually from $1{\cdot}65 \pm 0{\cdot}14$ to $60{\cdot}78 \pm 1{\cdot}84$ as would be expected. The data therefore reflect a low level of variation from mean stem length values for shoots where the short internode system is developing; and they clearly reflect increasingly greater and a relatively high level of variation where the long internode system is developing. This is one of the primary reasons why plastochron numbers based on mean stem length values would *not* be considered reliable.

(iv) *Lengths of successive internodes:* In the long and short internode system, considered as a unit, successive internodes, from the coleoptilar node to the last definitive node below the shoot apex, are progressively longer (Table IV, collection 19). In mature shoots the most basal internode had a mean length of 0·15 cm.; the uppermost internode, the peduncle, had a mean length of 27·8 cm. Internodes intercalated between these two had intermediate values in ascending order from the most basal internode.

Data in Table III reveal that the first internodes of the long internode system first become discrete internodes *after* transition to reproductive phase between plastochrons 10·2 and 10·4. However, the first internode (internode seven) of the long internode system is initiated prior to the transition phase. The other long internodes are initiated acropetally and prior to as well as during transition to reproductive phase;

their elongation and delimitation by formation of definitive nodal plates between them occurs during and after the transition phase.

In the most basal of the long internodes (number seven), elongation occurred during a period of 5·5 plastochrons (Table III). The other long internodes elongate over successively shorter periods. Elongation of all of the long internodes was completed by plastochron 12·8. Duration of elongation of the short internodes is more subtle and was not detectable by the techniques employed in these investigations. Their early stages of elongation have been treated in some detail at a histological level (Kaufman, 1959).

Data on lengths of internodes for mature shoots have been expressed in two ways in Table IV. The first set of values (*a* series) represents expression of internode lengths for *all* twenty plants in the sample irrespective of variation in the number of internodes present in the shoots measured. The second set of values (*b* series) represents mean internode length values obtained on the basis of the actual number of internodes *present* in the shoots examined. Hence, in the *a* series the lengths of the long internodes diminish from the most basal to the uppermost of these internodes, whilst the lengths of the internodes in the *b* series increase in the same direction. The former values reflect the status of internode lengths for the sample as a whole; the latter reflect the trend in internode length values that one would encounter in any given mature shoot in the late reproductive phase.

TABLE III. MEAN LENGTHS OF SUCCESSIVE INTERNODES IN MAIN AXES OF RICE SHOOTS (VARIETY CENTURY PATNA 231) OBTAINED FROM SEEDLING TO LATE REPRODUCTION STAGES OF DEVELOPMENT

	Collection number	Age of plants (days)	Plastochron number	Mean lengths[1] (cm.) of successive internodes from coleoptilar node[2] to youngest definitive node below shoot apex							
				1	2	3	4	5	6	7	8
	1	0	0								
	2	7	1·0								
	3	13	1·0								
Tr.[3] Vegetative phase	4	20	2·0	0·17							
	5	27	3·2	0·16	0·04						
	7	52	5·6	0·14	0·12	0·12	0·11	0·04	0·004		
	8	56	6·2	0·17	0·11	0·13	0·14	0·11	0·03		
	9	70	7·3	0·21	0·13	0·15	0·17	0·18	0·11	0·08	
	10	77	7·4	0·24	0·15	0·16	0·19	0·19	0·13	0·03	
	11	84	7·7	0·24	0·18	0·20	0·20	0·22	0·14	0·05	0·003
	12	91	8·5	0·23	0·17	0·19	0·21	0·24	0·30	0·14	0·04

TABLE III. (Contd.)

	Collec-tion num-ber	Age of plants (days)	Plasto-chron num-ber	Mean lengths[1] (cm.) of successive internodes from coleoptilar node[2] to youngest definitive node below shoot apex													
				1	2	3	4	5	6	7	8	9	10	11	12	13	14
	13	98	10·2	0·21	0·14	0·15	0·19	0·21	0·28	0·37	0·21	0·10	0·03	0·003			
Reproductive phase	14	105	10·4	0·21	0·14	0·16	0·21	0·24	0·36	0·48	0·31	0·11	0·03				
	15	112	11·0	0·16	0·16	0·18	0·19	0·24	0·43	1·67	1·12	0·61	0·10	0·02			
	16	119	11·1	0·12	0·14	0·17	0·21	0·24	0·50	1·93	2·55	2·11	0·98	0·47			
	17	128	11·3	0·13	0·12	0·14	0·17	0·21	0·43	2·06	3·23	2·87	1·67	0·29	0·02		
	18	142	11·6	0·10	0·12	0·13	0·16	0·19	0·29	2·06	4·38	8·02	13·79	12·10	2·44		
	19	177	12·8	0·15	0·16	0·23	0·26	0·59	0·78	2·25	4·29	7·93	12·84	14·90	12·49	4·17	

[1] Each value is computed on basis of N = 25 for collections 4 and 5; N = 20 for collections 4 to 19. Internodes present but not separated by definitive nodal plates were counted as zero.
[2] Internode 1 is internode immediately above the coleoptilar node.
[3] (Tr.) = transition to reproductive phase.

TABLE IV. MEAN LENGTHS OF SUCCESSIVE INTERNODES OF MAIN AXES OF RICE SHOOTS (VARIETY "CENTURY PATNA 231") AT PLASTOCHRON 12·8 (PLANTS 176 DAYS OLD)

Mean number of definitive nodes[1]	Method of expressing data	Mean lengths of successive internodes from coleoptilar node[2] to youngest definitive node below shoot apex[3].												
		1	2	3	4	5	6	7	8	9	10	11	12	13
12.80	a[4]	0·15	0·16	0·23	0·26	0·59	0·78	2·25	4·29	7·93	12·84	14·90	12·49	4·17
12.80	b[5]	0·15	0·16	0·23	0·26	0·59	0·78	2·25	4·29	7·93	13·52	18·63	24·99	27·80
		Short basal internode system						Extend upper internode system						

[1] Sample size = 20 plants
[2] Below internode No. 1
[3] Above internode No. 13
[4] Mean internode lengths for internodes 1 to 13 where means were computed on basis of N = 20. Internodes present but not separate by definitive nodal plates were counted as zero.
[5] Mean internode lengths for internodes 1 to 13, where means were computed on basis of N = 20 for internodes 1 to 9, N = 19 for internode 10, N = 16 for internode 11, N = 10 for internode 12, N = 3 for internode 13. N=number of plants having x number of internodes in the sample of 20 plants.

If one plots the number of definitive internodes formed per plastochron (Fig. 10), an approximately straight line relationship is obtained; the slope of this line indicates that approximately one definitive internode is formed per plastochron. Plotted on a time basis, the rate of internode formation is about one definitive internode per ten days with a decided diminution in rate of formation during late reproductive phase. One can, therefore, say for the Century Patna 231 variety of rice and under the conditions of this experiment, the plastochron interval for rate of appearance of definitive internodes (Fig. 10), and definitive nodes as well (Fig. 8), was ca. ten days. This value, of course, will vary with other varieties of rice and with different environmental and nutritional regimes.

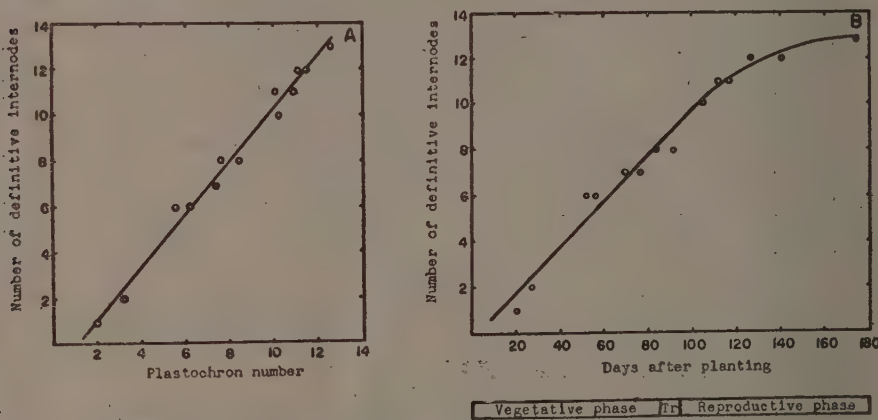

FIG. 10. NUMBER OF DEFINITIVE INTERNODES IN MAIN AXES OF RICE SHOOTS (VARIETY CENTURY PATNA 231) AT SUCCESSIVE STAGES OF SHOOT DEVELOPMENT.

(v) *Dry weight of stems:* The dry weight curve (Fig. 11) for stems obtained at successive stages of development, plotted according to successive plastochrons, has a distorted sigmoid shape. A long-term subtle increase in dry weight occurs during the vegetative phase of shoot development, which continues through transition to reproductive phase. After plastochron 11, the rate of increase in stem dry weight accelerates markedly from a level of 150 mg. to 1,150 mg.; this remarkable growth rate occurs in a period of a single plastochron (ca. 11·5 to 12·5). The more subtle increase in stem dry weight that occurs in vegetative phase, by contrast, changes only from 0·4 to 90 mg. during a period of ten plastochrons.

The curve for increase in dry weight of stems is similar to that for increase in stem length except for reproductive phase. When one plots stem dry weight against stem length an approximately straight line slope is obtained for most of the vegetative phase. The slope of the curve is considerably steeper for the seedling and reproductive phases, indicating that a greater increase in dry weight per unit increase in stem length occurs during these periods. Such changes in slope coincide respectively with formation of the first of the short internodes in seedlings and elongation of the long internodes in shoots in reproductive phase.

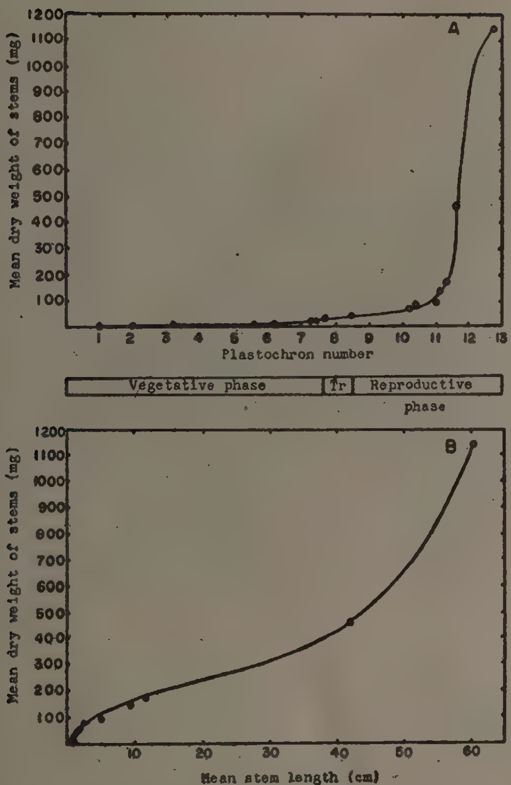

FIG. 11. MEAN DRY WEIGHTS OF STEMS OF MAIN AXES OF RICE SHOOTS (VARIETY CENTURY PATNA 231) FROM SEEDLING TO LATE REPRODUCTIVE STAGES OF SHOOT DEVELOPMENT, PLOTTED AS A FUNCTION OF PLASTOCHRON NUMBER (A) AND STEM LENGTH (B).

DISCUSSION

To assess stages of development of whole shoot or of shoot apex, leaf and stem, one must resort to both quantitative and qualitative methods. For whole shoots, reliance *in toto* on chronologic age or shoot height is unsatisfactory. The vagaries of the environment impinge on shoot development to such a marked extent that these criteria for stage of development are not meaningful or reliable in consecutive experiments or in experiments that might be duplicated. Clearly, it has been demonstrated with rice in these studies, and with other grasses (Andersen, 1952 and 1954; Bonnett, 1935, 1936, 1937, 1940 and 1953; Evans and Grover, 1940; Noguchi, 1929; Sharman, 1942 and 1947), that an actual count of leaf number and node number *or* measurement of stem length and inflorescence length or assessment of shoot apex (vegetative and reproductive) stage of development is decidedly more reliable and instructive.

Sharman (1942) has presented a plastochronic treatment of shoot development at a histologic level for *Zea mays*. A similar type of synopsis was given for shoots of *Oryza sativa* (Kaufman, 1959). These resumes serve admirably for descriptive purposes; and they describe development of a shoot or components of the shoot on a qualitative basis that is related directly to its morphogenesis. The present investigation attacks the problem of stem development in the rice shoot in a similar fashion but at a gross morphologic level and with more quantitative methods. The writer is in agreement with Erickson and Michelini (1957) that a plastochron index is a most useful tool to relate different parameters of growth of an organ, as the stem or leaf, directly with morphogenesis of that organ on a mathematical basis. It is unfortunate that the grass shoot eludes this type of treatment.

The grand phase of stem elongation in rice and other grasses (Prat, 1935) is of remarkably short duration in contrast with stem elongation in many other groups of plants. Moreover, the fact that this surge of growth in the stem is preceded by a long period of relatively insignificant elongation of earlier formed internodes presents a challenging morphogenetic question: what are the causal relations that explain the shift from leaf initiation and elongation, with concomitant formation of a short internode system, that occurs during the long vegetative phase of shoot development, to rapid and extensive elongation of later formed internodes during and after transition to reproductive phase of shoot development?

SUMMARY

A quantitative analysis of stem development in the Century Patna 231 variety of *Oryza sativa*, examined from seedling to late reproductive stages of shoot development, is presented in this paper. Successive stages of stem development are expressed on the basis of plastochron numbers which relate directly to number of definitive nodes at any given stage of shoot development. The parameters, node number, stem length, internode length and stem dry weight, are considered in detail in relation to chronologic time and plastochron number. Stem elongation is shown to be subtle and at a low level of magnitude during vegetative phase, whilst during and after transition to reproductive phase, it is the dominant feature of shoot development both in terms of its short duration and the relatively great extension of the internodes which have their genesis during late vegetative phase.

ACKNOWLEDGEMENTS

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REFERENCES

ANDERSEN, S. 1952. Methods for determining stages of development in barley and oats. *Physiol. Plant.* **5**: 199-210.

——— 1954. A method for determining stages of development in wheat. *ibid.* **7**: 513-16.

ANDERSON, E. and SCHREGARDUS, D. 1944. A method for recording and analyzing variation in internode pattern. *Ann. Mo. Bot. Gard.* **31**: 241-47.

BONNETT, O. T. 1935. The development of the barley spike. *J. agric. Res.* **51**: 451-57.

——— 1936. The development of the wheat spike. *ibid.* **53**: 445-51.

——— 1937. The development of the oat panicle. *ibid.* **54**: 927-31.

——— 1940. Development of the staminate and pistillate inflorescences of sweet corn. *ibid.* **60**: 25-37.

——— 1953. Developmental morphology of the vegetative and floral shoots of maize. *Univ. Ill. agric exp. Sta. Bul.* : 568.

BROWN, W. V. 1959. The epiblast and coleoptile of the grass embryo. *Bull. Torrey bot. Club* **86**: 13-16.

ERICKSON, R. O. and MICHELINI, F. J. 1957. The plastochron index. *Amer. J. Bot.*, **44**: 297-305.

EVANS, M. W. and GROVER, F. O. 1940. Developmental morphology of the growing point of the shoot and inflorescence in grasses. *J. agric. Res.* **61**: 481-520.

JOHNSON, V. A. 1954. Culm morphology and development in winter wheat. *Bot. Gaz.* **115**: 278-84.

JULIANO, J. B. and ALDAMA, M. J. 1937. Morphology of *Oryza sativa* L. *Philippine Agriculturist* **26**: 1-134.

KAUFMAN, P. B. 1959. Development of the shoot of *Oryza sativa* L. III. Early stages in histogenesis of the stem and ontogeny of the adventitious root. *Phytomorphology* (*In Press*).

MAJUMDAR, G. P. and SAHA, B. 1956. Nodal anatomy and the vascular system of the shoot of rice plant (*Oryza sativa* L.). *Proc. Nat. Inst. Sci. India* **22**: 236-45.

NILSON, E. B., JOHNSON, V. A. and GARDNER, C. O. 1957. Parenchyma and epidermal cell length in relation to plant height and culm internode length in winter wheat. *Bot. Gaz.* **119**: 38-43.

NOGUCHI, Y. 1929. Studien über die Entwicklung der Inflorezenzen und der Blüten bei Getreidepflanzen. *J. Coll. Agr. Imp. Univ. Tokyo* **10**: 247-304.

PALMER, J. H. 1958. Studies in the behaviour of the rhizome of *Agropyron repens* (L.) Beauv. *New Phytol.* **57**: 145-59.

PRAT, H. 1935. Recherches sur la structure et le mode de croissance des chaumes. *Ann. Sci. Nat.* (*Bot.*) *Ser.* 10 **17**: 81-145.

SHARMAN, B. C. 1942. Developmental anatomy of the shoot of *Zea mays* L. *Ann. Bot.* **6**: 245-82.

——— 1947. The biology and developmental morphology of the shoot apex in the Gramineae. *New Phytol.* **46**: 20-34.

INTERVARIETAL DIFFERENCE TO THE PHOTOPERIODIC RESPONSE IN BLACK GRAM AND ITS TETRAPLOIDS

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One of the two plants with which the phenomenon of photoperiodism was demonstrated by Garner and Allard (1920) is a seed legume, the Biloxi soybean. It is interesting to find that the majority of the seed legumes are short-day plants and some of them are very sensitive to it. Within the genus *Phaseolus*, the scarlet runner bean (*P. coccinus*) is a long-day plant. Allard and Zaumeyer (1944) observed considerable varietal difference in the common bean (*P. vulgaris*) and lima bean (*P. lunatus*), where in addition to the short-day ones some of the varieties behaved like day-neutral plants. Varietal difference in their response to the seasonal and photoperiodic effects was also found in green gram (*P. aureus*) by Sen Gupta and Mukherjee (1949), one variety being a short-day plant and the other a long-day one. Results obtained in this laboratory indicate that most of the varieties of green gram, which can be grown in the *kharif* season at Kharagpur are day-neutral plants and those grown in the *rabi* season are short-day plants. The day-neutral character is of considerable advantage for breeding varieties adapted to cultivation under a wide range of seasonal conditions, and this has been utilized specially in bean breeding.

In India, black gram (*P. mungo*) is cultivated both in the *kharif* (warm and long days) and *rabi* (cool and short days) seasons. At Kharagpur, the *kharif* varieties can be grown in the *rabi* season, though the yield is reduced; but the *rabi* varieties when sown in the *kharif* season have a prolonged vegetative period with a greatly reduced seed yield, making them suitable as a fodder legume. It was thought that the difference in their photoperiodic requirements is the major cause of such behaviour; and that it will be possible to hasten or retard flowering in black gram varieties by controlling the photoperiod. This will considerably facilitate a genetical and breeding programme by bringing the varieties to be hybridized to flower together and growing more generations per year.

The present study has been limited to one *kharif* and two *rabi* varieties. As autotetraploids of each were available (Sen and Chheda, 1958) and very little is known about the response of the autotetraploids in general to the photoperiodic treatment, these were also included.

MATERIAL AND METHODS

The experiment was conducted in the *kharif* and *rabi* seasons of 1957. Three pure strains—T 9 of Cawnpore, NP 14 of Pusa and ST 8 of Sabour were used.

The plants were grown in 12-inch pots with well manured soil and the sowing was done on June 10 and September 20, 1957, respectively. Three seeds were sown in each

pot, thinned to one seedling per pot after a week. Half the number of plants in each variety in the *kharif* sowing were exposed to a ten-hour daily photoperiod, screening off the daylight in the afternoon in a specially prepared dark chamber from the date of thinning, i.e., one week after sowing or two to three days after germination. There were six to ten plants per treatment.

The dates of bud initiation and flowering and the node on the main stem from which the first inflorescence arose were recorded, as also success in hybridization in the diploids of the treated plants. The plants were hybridized by the usual method followed for black gram—emasculating the buds due to open the next day in the afternoon, pollinating the next morning, and covering the flowers with oil-paper bags. The hybrid seeds were grown in the *rabi* season of that year.

OBSERVATIONS

The mean time required to flower from the date of sowing, the node number from which the first inflorescence arose in the three varieties of black gram and their tetraploids when sown in the *kharif* and *rabi* seasons, and the effect of these characters due to short photoperiodic treatment in the June sowing when the day-lengths are long, are given in Table I.

TABLE I. THE EFFECTS OF SOWING TIME, PLOIDY AND PHOTOPERIOD ON THE MEAN FLOWERING TIME AND FLOWERING NODE

Variety	Sowing time	Treatments	Ploidy	Flowering time in days	Flowering node number
T 9	June	Control	2n	38·36±1·041	5·13±0·118
			4n	45·73±1·864	4·64±0·064
		10 hrs.	2n	36·58±0·097	5·08±0·097
			4n	38·44±0·140	4·82±0·075
	Sept.	Control	2n	40·78±1·403	4·87±0·674
			4n	43·29±1·067	4·25±0·198
NP 14	June	Control	2n	85·74±2·384	15·48±1·688
			4n	87·00±1·860	14·76±1·063
		10 hrs.	2n	41·38±0·118	5·86±0·075
			4n	40·92±0·862	5·28±0·162
	Sept.	Control	2n	42·58±1·798	5·49±0·893
			4n	47·62±1·282	5·32±0·113
ST 8	June	Control	2n	94·43±1·469	16·28±1·047
			4n	87·06±2·380	14·57±0·873
		10 hrs.	2n	42·50±0·872	6·29±0·162
			4n	42·97±0·138	5·68±0·824
	Sept.	Control	2n	48·44±1·041	5·63±0·824
			4n	53·27±1·155	5·36±0·136

Among the three varieties (T 9, NP 14, ST 8), T 9 took about 40 days to flower both in the *kharif* and *rabi* sowings. The other two varieties, NP 14 and ST 8, took much longer to flower in the *kharif* season than in the *rabi*. In both the sowings, ST 8 flowered about a week later than NP 14. Of the major environmental changes in the two seasons, which are known to have considerable effect on flower initiation, both the day-length and temperature were falling June onwards.

The exposure to a ten-hour short photoperiod in the June sowing, when the days are the longest in the year, did not affect the variety T 9 much, but induced early flowering in NP 14 and ST 8 by about 44 and 52 days, respectively. The prolonged vegetative period made these plants much larger than the early fruiting treated plants, giving a contrasting appearance comparable to the classical photograph of the similarly treated Biloxi soybean of Garner and Allard (1920). Some of these plants developed the leaf-spot disease and the number of fruits per plant was comparatively meagre. From the results of the June sowing, it is apparent that there are two distinct groups in black gram which can be called as day-neutral and short-day types.

The variety T 9 flowered more or less in the same time in all the three treatments, though a couple of days earlier in the ten-hour photoperiod and a couple of days later in the colder days of the September sowing. Thus, neither the photoperiod nor temperature under experimental conditions had any major effect on the flowering in this variety. The varieties NP 14 and ST 8, on the other hand, flowered much earlier in the September sowing when the day-length and temperature were considerably reduced. More or less similar, or a little more, earliness could be induced by exposing these plants to a ten-hour photoperiod in June when the temperature is quite high. Thus, under the conditions of this experiment, the temperature has little and photoperiod a marked effect on the flowering in these two varieties of black gram.

The behaviour of autotetraploids was more or less similar to their respective diploids with respect to flowering. In the June sowing, the autotetraploids of the early T 9 flowered a week later than the diploid, but a couple of days later in the NP 14 and a couple of days earlier in ST 8, where the flowering was delayed the most. In the September sowing, the tetraploids flowered three to five days later than the respective diploids.

When exposed to a short photoperiod in June, the response of the tetraploids resembled that of diploids—all the three varieties flowering within 38 to 41 days. The delay in flowering of the tetraploids in normal sowing time (June for T 9 and September for NP 14 and ST 8) was reduced when both were exposed to a short photoperiod.

The node at which the first inflorescence arises on the main stem is seen to be determined more or less by the time the plants take to flower. When the plants flower early, irrespective of the variety, sowing time or treatment, the first inflorescence arises between the 4th and 6th nodes. But when the flowering is delayed till 85th to 95th day, about ten more internodes develop. The tetraploids generally flower in a node which is on a lower level than that on their respective diploids, even though they flower a little later.

As the plants of all the three varieties exposed to the ten-hour photoperiod flowered in about 40 days, it was possible to intercross them with normally widely

different flowering times. Among T 9, NP 14 and ST 8, altogether 68 crosses were made of which 42 succeeded. However, the percentage of success in black gram is normally over 80 per cent. As the black gram seeds have no dormancy period, the F_1 progenies could be raised in October of the same year. Therefore, the induction of early flowering in the late varieties by a short photoperiodic treatment in the *kharif* season has made it possible to hybridize and grow the hybrid generation in the same year, thus saving a year in a genetical and breeding programme.

DISCUSSION

As in most crop plants, intervarietal difference in the time required to flower from the date of sowing is known in black gram, and Bose (1932) used this as one of the characters for classifying Indian black grams. Consciously or unconsciously, growers have evolved these for adaptability to the growing season of their localities, mostly through a selection of random mutations.

The results of this study indicate that the flowering time is considerably affected by the prevailing photoperiod of growing seasons in black gram, and intervarietal difference to the photoperiodic response exists. Among the three varieties studied, NP 14 and ST 8 can be classified as short-day plants and T. 9 as a day-neutral plant, according to Garner and Allard's (1920) terminology. Photoperiodic adaptation has thus played a part in the origin of varieties. We are inclined to believe that by conducting a selection, exposing the plants to near their critical day-length for flower initiation, considerable correlation between the time required to flower and the critical photoperiod for the varieties may be revealed.

Due to their short photoperiodic nature, varieties such as NP 14 and ST 8, grown in the long days have excessive vegetative growth and can be used as fodder. They are suitable as a seed crop in the *rabi* and *zaid* seasons. The day-neutral T 9 can be grown in all the three seasons; the yield, of course, will depend on several other factors.

The temperature has a considerable effect on growth and most of the 30 varieties in our collection do not grow well if the sowing is delayed beyond October—a limitation for getting a good yield of black gram as a late *rabi* crop at Kharagpur. But temperature seems to have little direct effect on the onset of flowering in this plant.

The tetraploids tend to flower about a week later than their diploids in normal sowing time. But when the flowering is delayed, as in the June sowing of NP 14 and ST 8, the difference is nullified. The tetraploids also grow slowly and the node at which the first inflorescence arises is at a slightly lower level, even though the flowering is delayed and a direct correlation is seen between the flowering node and the length of the vegetative period. When exposed to a short photoperiod they behave like their diploids, flowering considerably early in NP 14 and ST 8 but with little effect on the day-neutral T 9. It is of considerable interest to see that the general delay in flowering due to tetraploidy is nullified when both are exposed to a short photoperiod.

In most of the plants critically studied, it has been found that the tetraploids grow slowly, bloom later and have a much longer flowering period than their respective diploids. Seed legumes are no exceptions to this, as seen in the tetraploids of gram

(Ramanujam and Joshi, 1941), *arhar* (Bhattacharjee, 1956), green gram (Kumar, 1945), etc. The slower growth has been attributed to several factors like the reduced rate of cell division, smaller amount of growth hormone, slower rate of metabolic activities, etc. The hormonal nature of the substance responsible for the induction of floral promordia has now been well established. Still there is a controversy as to whether the control of flowering through photoperiodic exposure is through changing the level of the growth hormone, the auxin or through direct or indirect accumulation of some flowering hormone, the florigen, in the plants. Our knowledge of the rapid biochemical changes associated with the initiation of flowers is meagre and the chemical nature of the flowering hormone is still unknown. How the flowering in the tetraploids is delayed, especially how the difference with the diploid is nullified by exposure to a short photoperiod in black gram even in the day-neutral variety, should be a subject of considerable interest.

This investigation has shown that by a simple short photoperiodic exposure, the different varieties can be induced to flower in the long days of the *kharif* season, hybridized, and the hybrid generation grown in the *rabi* season of the same year. This will save a year in a genetical and breeding programme in this crop. If necessary, the cycle can be reversed, i.e., hybridizing in the *rabi* season, raising the F_1 plants in the *kharif* under a short photoperiod, and then growing the F_2 plants in the *rabi* season of that year.

SUMMARY

In black gram (*Phaseolus mungo*), intervarietal difference in time taken to flower and response to photoperiods are seen. The var. T 9 flowered in about 40 days when sown in June and September, while NP 14 and ST 8 took 85 and 94 days in the June sowing and 42 and 48 days in the September sowing. An exposure to a ten-hour photoperiod in the June sowing, when the plants are normally exposed to long days, did not affect the flowering time in T 9 but induced flowering in NP 14 and ST 8 in about 40 days. Thus, two distinct groups of black gram exist—day-neutral and short-day types.

Under the conditions of the experiment, temperature had a considerable effect on the vegetative growth but little on flowering, which was mostly determined by the existing photoperiod.

The autotetraploids behave like their respective diploids as regards the flowering time in the two sowings and in the photoperiodic treatment. They generally flowered about a week later, but the delay was nullified when both were grown under a short photoperiod.

The three varieties with a wide difference in the flowering time in the June sowing could be forced to flower simultaneously by a short photoperiodic treatment, hybridized, and the hybrid generation grown in the *rabi* season of the same year.

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REFERENCES

Allard, H. A. and Zaumeyer, W. J. 1944. Responses of beans (*Phaseolus*) and other legumes to length of day. *Tech. Bull. U.S. Dep. Agric.* **867**: 1-24.

Bhattacharjee, S. K. 1956. Study of autotetraploid *Cajanus cajan* (L.) Mill. *Caryologia* **9**: 149-61.

Bose, R. D. 1932. Studies in Indian Pulses No. 5. *Urid* or black gram (*Phaseolus mungo* Linn var. Roxb.). *Indian J. agric. Sci.* **3**: 1045-56.

Garner, W. W. and Allard, H. A. 1920. Effect of relative length of day and night and other factors of the environment on growth and reproduction. *J. agric. Res.* **18**: 553-606.

Kumar, L. S. S. 1945. A comparative study of autotetraploid and diploid types of green gram (*Phaseolus radiatus* L.). *Proc. Indian Acad. Sci.* **21**: 266-68.

Ramanujam, S. and Joshi, A. B. 1941. Colchicine induced polyploidy in crop plants. I. Gram (*Cicer arietinum* L.). *Indian J. agric. Sci.* **11**: 835-49.

Sen, N. K. and Chheda, H. R. 1958. Colchicine induced tetraploids of five varieties of black gram. *Indian J. Genet.* **18**: 238-48.

Sen Gupta, J. C. and Mukherjee, D. K. 1949. Studies on the physiology of growth and development of *mung* (*P. aureus*). *Indian J. agric. Sci.* **19**: 207-52.

STUDIES ON GREEN ROUGHAGES IN GUJARAT

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Green fodders, being nutritious, palatable and rich in carotene, are considered superior to dry fodders. As reported by Woll (1917) and Das Gupta (1941), alfalfa or berseem can replace 75 to 100 per cent of concentrate for milch animals without having any ill effect on the milk production. Sen (1952), while compiling the nutritive values of different fodders, recommended that dry animals may be maintained on good quality green fodder alone to reduce the cost of feeding and ultimately that of milk production.

Studies on local fodders in C.P. and Berar were made by Aiyer and Kayastha (1931) and of those in Burma by Narayanswami (1946). Similar studies were undertaken by Parthasarthy (1947), Das Gupta (1947), Muthunayagam *et al.* (1950) and Talapatra and Dev Goswami (1949) on the local grasses and fodders of Madras, U.P., Travancore and Assam, respectively. Patel *et al.* (1950) observed Guinea grass to be superior to Napier grass and elephant grass. Similar results were also obtained by Singh and Malik (1950).

In Gujarat, only about 10 per cent of the total cultivable area is under fodder crops like *jowar*, maize, lucerne, Guinea grass, etc. Moreover, the grasses growing on the boundaries of fields during monsoon are utilised as green fodders for the cattle. The present study gives an account of the composition of such green fodders commonly fed to cattle.

MATERIAL AND METHODS

Samples of various fodders were collected from four representative villages. Each village was divided into four blocks and samples were taken from several places in each block. All the samples from the four blocks were mixed, and the composite sample thus prepared was taken to represent the village. Composite samples of the pasture grasses were collected from the replicates of agronomical plots at the Institute.

The methods adopted for analysis were those recommended in A.O.A.C. (1950). All the results tabulated are on oven-dry basis and the figures in brackets therein indicate the number of samples analysed.

For the sake of convenience in the comparison of fodders, the results are presented in the following four groups.

(i) Cultivated fodders, (ii) pasture grasses, (iii) *shedha* grasses (grasses growing on the boundaries of fields) and weeds, and (iv) pulses as green fodders.

OBSERVATIONS

(i) *Cultivated green fodder:* Among the cultivated green fodders, *jowar* is the most common fodder grown in this tract, while lucerne and Guinea grass are now being

TABLE I. COMPOSITION OF CULTIVATED GREEN FODDERS

Fodder	C. protein Av. with range	E. extract Av. with range	N.F.E. Av. with range	C. fibre Av. with range	Phosphorus Av. with range	Calcium Av. with range
Lucerne (14) *Medicago sativa*	19·9(15·6–23·1)	2·9(1·9–4·4)	43·3(35·4–50·4)	22·9(13·0–31·9)	0·43(0·35–0·52)	1·59(1·29–1·96)
Berseem (6) *Trifolium alexandrinum*	15·6(11·1–18·6)	3·0(2·4–3·7)	41·6(39·4–45·1)	25·5(20·1–29·0)	0·36(0·31–0·41)	1·39(1·31–1·50)
Guinea grass (22) *Panicum maximum*	9·5(5·0–14·3)	2·0(1·2–2·9)	42·7(35·7–52·7)	30·1(23·4–40·8)	0·39(0·13–0·97)	0·66(0·35–0·98)
Maize (5) *Zea mays*	4·1(3·3–5·1)	1·1(0·6–1·5)	47·7(35·9–59·3)	38·0(26·9–50·8)	0·23(0·19–0·33)	0·37(0·31–0·49)
Jowar (4) *Andropogon sorghum*	5·0(4·6–5·7)	1·9(1·1–2·6)	51·2(44·8–57·7)	33·2(29·4–38·2)	0·31(0·25–0·34)	0·40(0·23–0·71)
Oats (4) *Avena sativa*	5·1(5·0–5·3)	2·5(2·5–2·6)	47·0(46·0–48·2)	35·4(34·3–37·1)	0·31(0·27–0·37)	0·31(0·28–0·34)

appreciated by the farmers. Samples of such fodders at the stage when they are usually harvested for feeding to cattle were collected for analysis. Lucerne, berseem and Guinea grass are harvested every three to four weeks and maize, *jowar* and oats in their dough stage. The results of the nutrient contents of these fodders are given in Table I.

The leguminous fodders, lucerne and berseem, are quite rich, having about 19 per cent protein. They are also rich in minerals and particularly calcium is as high as 1·5 per cent which is easily available to animals, as reported by Armstrong and Thomas (1952). Both these fodders are almost similar in composition, except that berseem is somewhat lower in protein.

Among the non-leguminous green fodders, Guinea grass having a protein content as high as 9·5 per cent, is superior in composition. *Jowar*, which is an important fodder crop of this tract, is quite rich in N.F.E., while it is lower in other nutrients. Inferiority of *jowar* fodder as compared to other green fodders is also reported by Lander and Dharmani (1936). This may probably be the result of harvesting the fodder in its advanced stage of growth to avoid hydrocyanic acid in its younger stage. Compositions of all these fodders are quite in agreement with those reported by Paul (1954), except that the protein content of oats of this area is only 6·1 per cent which is considerably low as compared to 14·6 per cent reported by him.

(ii) *Pasture grasses:* As reported by Walker *et al.* (1953) and Chamblee *et al.* (1953) pasture grasses vary in composition, depending upon the stage of growth, manuring, species, seasons,etc. In order to have a comparative idea of the composition of various pasture grasses, samples of such grasses grown on the Institute farm for agronomical trials were taken in their flowering stage. This would delete the effect of all other factors on their composition except the species difference. The composition of such pasture grasses is given in Table II.

From Table II it is evident that most of the *Panicum* grasses, *Chloris geryana* and *Desmudus unicinatum* are superior in protein to other grasses as they have 8 to 13 per cent protein. The protein content in all other grasses varies from five to eight per cent except in *Pennisetum ciliaris*, *Andropogon ischemum* and *Ischilema wightii* which have only about three per cent. *Sorghum sudanesis* has the highest amount (56·1 per cent) of N.F.E. With regard to minerals, *Panicum muticum* has phosphorus content as high as 0·82 per cent and *Pennisetum purpurium* and *Pennisetum cenchroides* are fairly rich having about 0·6 per cent phosphorus. *Panicum antidotale*, *Andropogon ischemum* and *Desmudus uncinatum* are rich in calcium, the last having more than one per cent. On the whole, *Desmudus uncinatum*, *Chloris geryana* and *Panicum antidotale* are better grasses among the lot.

(iii) Shedha *grasses and weeds:* Various grasses grow in monsoon of their own accord in the fields and on their uncultivated boundaries. These grasses vary in nature from village to village and quite often even from field to field. Samples of such weeds and *shedha* grasses were collected from ten villages and the average results of the same type of grasses with their standard error are given in Table III.

Composition of several *shedha* grasses is comparable to and a few even superior to that of cultivated fodders. *Bhumsi*, for example, which has a high protein content of 11·6 per cent and phosphorus content of 0·46 per cent is richer than any of the

TABLE II. COMPOSITION OF EXOTIC GRASSES

Name	C. protein	E. extract	N.F.E.	C. fibre	Ash	Phosphorus	Calcium
Eragrostis chlorometus	6·8	1·4	48·4	37·0	6·4	0·29	0·38
Eragrostis superba B.N. 2031	5·3	1·1	47·3	39·4	6·9	0·41	0·30
,, B.N. 3941	5·3	1·6	49·3	36·0	7·8	0·28	0·23
Eragrostis curbula	5·2	1·7	45·6	36·4	11·1	0·31	0·35
Panicum sp.	8·0	1·3	42·7	34·9	13·1	0·40	0·36
Panicum antidotale	13·0	1·1	39·1	36·8	10·0	0·23	0·67
Panicum laevifilium	5·4	1·5	42·4	40·2	10·5	0·45	0·40
Panicum muticum	10·2	2·2	47·3	23·6	16·7	0·82	0·29
Panicum maximum	8·2	2·7	50·4	21·9	16·8	0·37	0·59
Green Panic	10·8	1·3	44·1	34·2	9·6	0·31	0·43
Pennisetum cenchroides	7·1	1·9	48·8	30·7	11·6	0·59	0·33
Pennisetum ciliaris	2·8	3·0	42·4	38·1	13·6	0·28	0·31
Pennisetum pedicellatum	7·4	2·8	49·0	22·2	18·6	0·41	0·42
Pennisetum purpureum	9·4	2·8	46·2	18·6	23·0	0·68	0·35
Pennisetum polystachyon	7·8	1·9	49·6	24·1	16·5	0·48	0·17
Andropogon ischemum	3·9	1·5	46·0	38·5	10·1	0·25	0·65
Andropogon contortus	7·5	1·9	47·8	35·7	7·1	0·27	0·45
Tricholaenia rosea	6·0	1·3	45·5	38·8	8·4	0·42	0·30
Dichnthium annulatum	7·9	1·4	43·5	36·5	10·8	0·33	0·31
Ischilema wightii	3·7	1.4	50·0	36·7	8·2	0·23	0·25
Chloris geryana	12·4	2·2	47·4	26·8	11·2	0·42	0·40
Marvel Selection V•	7·3	2·7	54·2	22·4	13·4	0·36	0·40
Sorghum sudanesis	7·2	2·0	56·1	24·8	10·8	0·49	0·46
Desmudus unicinatum	12·8	3·4	45·2	26·6	9·1	0·42	1·06
Cenchrus ciliaris	7·9	2·2	51·3	22·4	16·2	0·56	0·30

TABLE III. *SHEDHA* GRASSES AND WEEDS

Name	C. protein	E. extract	N.F.E.	C. fibre	Phosphorus	Calcium
Dhaman (14) *Pennisetum cenchroides*	7·8±0·63	1·6±0·27	43·6±1·85	33·7±3·08	0·21±0·04	0·50±0·05
Arotaro (4) *Paspalum sanguinate*	6·5±0·68	1·7±0·21	44·8±1·30	34·8±0·72	0·47±0·02	0·45±0·09
Karedi (4) *Apluda varia*	8·1±1·24	2·4±0·46	42·2±3·08	32·6±1·41	0·44±0·07	0·57±0·06
Zizvo (4) *Andropogon annulatus*	5·6±0·71	1·1±0·44	46·4±1·53	34·9±2·38	0·34±0·04	0·38±0·08
Bant (2) *Echinochloa colona*	5·2±0·32	1·8±0·72	45·7±0·32	34·8±1·82	0·24±0·04	0·37±0·03
Bhumsi (3) *Irrigratis major*	11·6±2·09	2·5±0·25	43·8±2·48	31·6±0·72	0·46±0·10	0·45±0·20
Chido (3) *Cyprus rotandus*	8·9±2·29	2·0±0·45	49·3±2·68	26·7±0·67	0·38±0·04	0·52±0·10
Dharo (2) *Cynadon ductylon*	11·0±1·67	1·2±0·24	51·5±0·30	20·7±2·20	0·31±0·07	0·91±0·21
Vakumbo (4) *Orobanchaceae* sp.	8·9±1·21	1·7±0·24	68·2±2·61	11·3±1·88	0·31±0·04	0·34±0·03
Garo creepers (4) X *Tinosporeae cordifolia*	11·2±0·61	2·5±0·26	61·0±2·09	17·5±0·98	0·57±0·02	1·06±0·14

cereal fodders given in Table I. *Dhaman*, *karedi* and *chido* having more than eight per cent protein can form a group fairly high in protein. Among them *chido* is least fibrous and is comparatively rich in all the nutrients. *Zinzvo* grass, though low in protein, is reported by Warth (1930) to be quite nutritive. Most of these grasses have fairly good amount of phosphorus but are poor in calcium. From the results it is evident that if the field boundaries are seeded with the seeds or stubbles of grasses like *bhumsi*, *Desmdus uncinatum*, or *Panicum antidotale* and properly treated, the quality of the fodder supply through this source can be improved to a great extent.

Among the weeds, *chido*, *dharo*, *vacumbo* and *garo* are quite common. They are quite high in protein probably because they are usually weeded out in young stage. They are also fairly rich in calcium and phosphorus and very low in crude fibre.

Orobanche parasite, being very widespread in tobacco fields of this area, is available in large quantities. It has as high 68·2 per cent N.F.E. and nine per cent protein and, therefore, can serve as a good fodder for work-animals. If a practice of weeding them out in their young stage is adopted, it would also serve as an efficient measure for their eradication. Vengris *et al.* (1953) similarly examined 26 species of weeds and observed them to be good competitors for N, P and K which made them more nutritious and useful as fodders.

(iv) *Pulses as green fodders:* Pulses are grown in Gujarat not solely for fodder purposes, but they are usually grown mixed with cereals. After the harvest of cereals, the pods of the legumes are plucked for human consumption and the leaves and tender stems, yet in green condition, utilised as green fodder for cattle. Average compositions of such fodders are given in Table IV, which also includes the composition of *wal* in its younger (flowering) stage.

TABLE IV. PULSES AS GREEN FODDERS

Name	C. protein	E. extract	N.F.E.	C. fibre	Phosphorus	Calcium
Chola (4) *Vigna catjang*	19·0±2·47	2·8±0·37	43·2±0·36	18·4±2·97	0·45±0·09	2·14±0·11
Math (4) *Phaseolus aconitifolius*	15·5±0·76	1·9±0·38	50·2±1·27	19·7±2·21	0·54±0·09	2·37±0·11
Mug (4) *Phaseolus aureus*	13·0±0·77	3·6±0·16	51·0±1·62	21·0±1·83	0·34±0·04	2·57±0·12
Wal (mature) (3) *Dolichos lablab*	12·6±1·87	2·9±0·36	45·4±2·07	26·0±2·52	0·28±0·04	2·80±0·33
Wal (flowering) (4) *Dolichos lablab*	23·4±0.98	3·3±0·30	41·2±2·62	22·0±1·59	0·50±0·04	2·24±0·34

From the results in Table IV it is apparent that *Dolichos lablab* in flowering stage has 23·4 per cent protein which is highest among all. However, it is not the usual practice to feed it in its flowering stage. Considering all other fodders in their mature stage after plucking the pods, it is apparent that all these fodders are quite rich in

protein, *chola* with 19 per cent protein being superior among them. If these fodders are not utilised in their possible green condition and allowed to get further matured and dried up, they become not only low in protein but also in ether extract and carotene as reported by Nelson *et al.* (1948). It is for these reasons that Ivins (1952) reported these fodders in green condition to be more palatable and nutritive than in their dry form.

Comparison of *wal* in two stages shows a significant variation in composition, particularly the protein content in flowering stage being almost double the amount present in advanced stage. This indicates that if such crops are thickly sown for fodder purposes they can provide good fodders rich in protein.

Most of these fodders are quite high in calcium content and their $CaO:P_2O_5$ ratios lie between 3:1 to 5:1 which is within optimum range for cattle as reported by Morrison (1949). Among these fodders, *chola* being rich in protein and minerals and low in fibre, is superior. It is quite comparable to lucerne and berseem which, as suggested by Das Gupta (1941), can replace concentrates to the extent of 50 to 75 per cent in the ration of milch cattle.

SUMMARY

Leguminous and cereal green fodders, exotic grasses, *shedha* grasses and weeds and pulses as green fodders are studied. Among the leguminous cultivated fodders, lucerne is observed to be superior while among non-legume fodders Guinea grass is superior. The study of *shedha* grasses, as major source of green fodder, indicated that if the field boundaries are reseeded with the seeds or stubbles of protein-rich grasses like *Desmudus uncinatum* or *Panicum antidotale*, the quality of such fodder can be improved to a great extent. The Orobanche parasite can easily be eradicated by feeding it to cattle in its young stage. Pulse fodders are so rich in protein that if properly utilised they can help in reducing the concentrate feeding.

REFERENCES

Aiyer, A. R. P. and Kayastha, R. N. 1931. *Agric. and Livestock in India* **1**: 526.
Association of Official Agricultural Chemists. 1950. *Official and Tentative methods of Analysis.* The Association of Official Agricultural Chemists, Inc., Washington, D.C., U.S.A.
Armstrong, R. H. and Thomas, B. 1952. *J. agric. Sci.* **42**: 454.
Chamblee, D. S., Lovvorn, R. L. and Woodhouse, W. W. (Jr.). 1953. *Agron. J.* **45**: 158.
Das Gupta, N. C. 1941. *Prog. Rpt. Cattle Feeding Res. Sch. I.C.A.R.*, U.P.
——— 1947. *Indian J. vet. Sci.* **17**: 34.
Ivins, J. D. 1952. *J. British Grassland Soc.* **7**: 43.
Lander, R. E. and Dharmani, L. C. 1936. *Indian J. vet. Sci.* **6**: 117.
Morrison Frank, B. 1949. *Feeds and Feeding.* Morrison Publishing Co., Ithaca, New York.
Muthunayagam, A. P. A. and Abraham, M. C. 1950. *Indian Dairyman* **3**: 68.
Narayanaswami, V. 1946. *Sci. and cult.* **11**: 536.
Nelson, W. L., Loostli, J. K., Logren, G. and Tangar, N. 1948. *Indian Eng. Chem.* **40**: 2196.
Parthasarthy, S. V. 1947. *Proc. Indian Sci. Congr.* **34**: 226.
Patel, N. M., Patel, B. M. and Patel, R. M. 1950. *Indian J. Dairy Sci.* **3**: 16.
Paul, T. M. 1954. *Indian Dairyman* **6**: 54.
Sen, K. C. 1952. *I.C.A.R. Misc. Bull.* 25.
Singh, R. and Malik, H. C. 1950. *Indian Fmg.* **11**: 521.
Talaptra, S. K. and Dev Goswami, M. N. 1949. *Indian J. vet. Sci.* **19**: 19.
Vengris, J., Drake, M., Colby, W. G., and Bart, J. 1953. *Agron. J.* **45**: 213.
Walker, T. W., Edwards, G. H. A., Cavell, A. J. and Rose, T. H. 1953. *J. Brit. Grassland Soc.* **8**: 45.
Warth, F. J. 1930. *Mem. Dept. Agric. India Chem. Ser.* **11**: 73.
Woll, F. G. 1917. *J. Dairy Sci.* **1**: 6.

STUDIES IN BUNDELKHAND SOILS OF UTTAR PRADESH
IV. MOVEMENT OF IRON AND MAGNESIUM IN THE PEDOGENESIS OF THE SOILS

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In a previous communication from this laboratory, Agarwal and Mukerji (1946) while discussing the chemical composition of the clay fractions of the three genetic soils of the Bundelkhand tract in relation to the processes of soil formation, observed that under the climatic and other conditions prevailing in the locality the ferro-magnesian minerals in the soils show the greatest amount of disruption. Although the silica-alumina ratios of the clay complex showed an essentially constant character in the three distinct soils, the iron oxide was shown to be affected differently. In this way, the characters of these soils looked pedo-genetically different from those of similar soils reported from the tschernozemic areas in other parts of the world. Further, it was observed that in the soils of the locality where the conditions became favourable for the segregation of iron oxide and its subsequent oxidation, the characteristic red colour was imparted to one of the members of the catena. This typical differential behaviour of iron was ascribed to higher temperatures prevailing in the subtropics which not only exert greater disruptive action on the ferro-magnesian minerals but also segregate iron and oxidise it to give the characteristic red colour.

Swensen and Riecken (1955), in their studies on the movement of iron in the development of the loess-derived soils of the U.S.A., found that the soil-forming factors under their conditions were such as to affect greatly the iron containing primary minerals, and they termed this process as "argisolization". In view of the greater importance of this soil-forming process in subtropical countries, where under identical conditions mixed red and black soils are encountered, it was thought necessary to study in a quantitative manner the movement of iron and magnesium in the different size-fractions of the genetically related soils of the Bundelkhand area with a view to throwing light on this process in the pedogenesis of the soils of this tract.

MATERIAL AND METHODS

Site characteristics, climate, vegetation and other soil-forming factors in the locality have already been described fully in the previous papers of this series. Soil samples from profiles considered typical were obtained from Bharari near Jhansi. Sites were so chosen that the three genetic soil types occur very close to each other, permitting a catena study of the entire soil system. Thus, the total distance between the three profiles selected was only 264 feet. The pits were dug in an east to west direction. The land had a higher elevation in the east with a rolling topography, i.e., Pit One representing the *Rakar* soil was situated at the top of the slope, while Pit Three representing the *Kabar* soil was at the bottom.

Organic matter in the soil was oxidised with hydrogen-peroxide (20 vol) and the mechanical size-fractions were separated according to the method of Robinson (1953). Finer fractions were separated by the usual method of sedimentation and decantation until final syphoning gave a clear supernatant liquid. Individual fractions so isolated were dispersed several times and separated to remove admixture of other fractions. Coarse sand was isolated through sieving. The fractions were then dried in the air and for purposes of analysis were ground to pass a 100-mesh sieve.

Total iron was estimated after fusion of the samples with sodium carbonate according to the standard method described by Piper (1950). Fusion was carried out in a muffle furnace at 875°C for 30 minutes after which the mass was extracted through hydrochloric acid. Free iron was removed from the fractions using an aqueous solution of sodium hydrosulphite as described by Mackenzie (1954) and estimated separately. Lattice iron was obtained by difference.

Iron determinations (both total and free) were made colorimetrically using sodium salicylate by the method proposed by Scott (1941). Colour comparisons were made on a Hilger Spekker Absorptiometer. Magnesium determinations were made volumetrically by precipitating it as magnesium ammonium phosphate.

OBSERVATIONS

The morphological characters of the three profiles corresponded with the descriptions recorded by Agarwal and Mukerji (1946) and the same have not been described here for the sake of brevity. In accordance with the terminology, later adopted for the three soil series by the U.P. Soil Survey Organisation (Agarwal and Mehrotra, 1952), the three soils have been named as *Rakar*, *Parwa* and *Kabar* series. The mechanical composition of the three soils is recorded in Table I. All calculations on the size fractions of the soil samples were made on the basis of the mechanical composition shown in this table.

TABLE I. MECHANICAL ANALYSIS OF THE SOILS

Laboratory No.		Depth	Coarse sand 2·0–0·2 mm.	Fine sand 0·2–0·02 mm.	Silt 0·02–0·002 mm.	Coarse clay 0·002–0·001 mm.	Fine clay <·001 mm.
Rakar	2,292	0–14″	56·00	24·06	7·14	6·76	6·04
	2,293	14–28″	46·41	14·13	9·75	15·80	13·85
	2,294	28–52″	65·60	14·79	6·71	7·11	5·79
Parwa	2,286	0–12″	34·67	31·11	11·76	12·13	10·11
	2,287	12–34″	23·08	24·02	12·11	22·28	18·51
	2,288	34–48″	19·19	23·28	19·35	21·08	17·10
Kabar	2,282	0–12″	7·32	29·40	24·97	20·79	17·52
	2,283	12–34″	6·47	27·73	24·29	21·62	19·89
	2,284	34–49″	6·98	28·79	25·00	23·06	16·17
	2,285	49–62″	36·02	25·58	12·84	14·45	11·11

Iron contents of the size-fractions

Data for the various forms of iron in different size-fractions of the three soils are given in Table II.

(a) *Total iron:* It is seen from Table II that the total iron content of the different size-fractions in the three soils increases with decrease in the particle size. Between the coarse and fine sands and between the coarse and fine clays, this increase is not so marked as that between sand and clay. This shows that during the weathering process the iron-containing minerals decompose, both physically and chemically, more rapidly as compared to the relatively resistant non-iron-containing minerals, and thus as the weathering progresses from sand to clay the resultant finer particles get enriched in iron contents. That iron also gets involved in forming secondary clay minerals, is also shown by the fact that the iron content of the fine clays gets stabilised at about 10 to 12 per cent. Hoore *et al.* (1954) while studying tropical clays and their iron contents also observed the most frequently occurring iron level in the clay fractions of the different tropical soils to be 10 to 12 per cent which correspond to the oxide saturation of the clay surface as observed through experimental fixation.

In general, there is an increase down the profile in the total iron content of the various size-fractions in the three soils. This increase is more marked in the coarse fractions as compared to the finer ones. Had this increase been associated with the degree of soil development, the trend should have been more pronounced in the finer particles which are subject to the greatest effect of weathering. Since it is not so, it appears that this increase is secondary and is perhaps due to the formation in the bottom layers of iron concretions of the silt and above size, which process is known to take place after the clay has been fully saturated with iron and there is excess of free iron in the soil system which on oxidation can form iron concretions round about soil particles. That this increase is maximum for the *Rakar* soil which is the most leached soil and liable to greatest oxidation lends support to the above hypothesis.

(b) *Free iron:* The contents of free iron (Table II) show a higher value in the finer fractions in *Rakar* soil than in the similar sized fractions in the *Parwa* and *Kabar* soils. Fine clay fraction in *Kabar* soil shows the highest value of free iron, ranging from 3·0 to 4·2 per cent. This value in the fine clay fractions in *Parwa* and *Kabar* soil varies from 1·1 to 2·0 and 0·7 to 1·7 per cent, respectively. A similar trend is visible in the coarse clays and silt fractions of the three soils. The order of decrease in the free iron contents in the three soils follows the order of the soil formation. It shows that the free iron formation is associated in the first stage of weathering of the soil and that subsequently this form of iron gets involved in concretion formation. A similar behaviour was also observed by Swensen and Riecken (1955) in the development of loess-derived Brunizem soils in the U.S.A. This is also in accordance with the observations on iron-nodules and concretion formation in many ferrugenous soils where the iron concretions are present as free-iron oxides.

Rakar, a predominantly red soil associate of the catena, though does not show much difference in the total iron content from the other two soils, yet it is in the higher values of free iron, specially in the silt and clay fractions, that the characteristic colour is perhaps due to. This becomes all the more prominent as the *Rakar* soil being high-lying is prone to greater oxidative regimes.

TABLE II. CONTENTS OF THE FORMS OF IRON IN DIFFERENT SIZE FRACTIONS OF THE SOIL

(Fe_2O_3 in gm. per cent)

Laboratory number		Coarse sand			Fine sand			Silt			Coarse clay			Fine clay		
		Total	Lattice	Free	Total	Lattice	Free	Total	Lattice	Free	Total	Lattice	Free	Total	Lattice	Free
Rakar	2,292	0·25	0·06	0·19	1·7	1·40	0·30	5·6	4·6	1·0	8·0	5·6	2·4	11·6	8·0	3·6
	2,293	0·55	0·35	0·20	2·0	1·64	0·36	6·2	3·8	2·4	7·0	3·9	3·1	10·8	6·6	4·2
	2,294	3·75	2·97	0·78	6·5	5·91	0·59	10·0	6·8	3·2	9·7	7·1	2·6	10·8	7·8	3·0
Parwa	2,286	0·35	0·12	0·23	1·4	1·19	0·21	4·0	3·4	0·6	8·5	6·1	2·4	11·2	9·2	2·0
	2,287	0·35	0·11	0·24	1·5	1·30	0·20	3·8	3·6	0·2	8·5	7·6	0·9	12·0	10·7	1·3
	2,288	0·65	0·34	0·31	1·6	1·38	0·22	3·4	2·9	0·5	8·0	7·4	0·6	11·2	10·1	1·1
Kabar	2,282	0·95	0·42	0·53	1·4	1·19	0·21	4·6	4·0	0·6	10·0	7·7	2·3	10·8	9·8	1·0
	2,283	1·80	1·10	0·70	1·5	1·26	0·24	5·0	4·5	0·5	9·5	7·4	2·1	11·2	9·5	1·7
	2,284	2·00	1·17	0·83	2·3	1·95	0·35	5·0	4·95	0·05	9·2	7·6	1·6	9·6	8·9	0·7
	2,285	1·15	0·77	0·38	3·3	2·78	0·52	5·6	5·5	0·1	9·0	8·1	0·9	10·8	9·8	1·0

The highest value for free iron, both for fine and coarse clay fractions, in *Rakar* soil occurred in the second horizon. But in the case of other fractions, viz., silt, fine and coarse sands, the highest value was recorded in the last horizon which is the horizon of *murrum* deposition in the profile.

(c) *Lattice iron:* From a general observation of the data in Table II it is observed that, like the total iron contents of the different fractions, the lattice iron contents also increase with the fineness of the particle size. If looked into for the lattice iron of fine clay, it is observed that it varies from 9·5 to 9·8 per cent in *Kabar* soil, from 9·2 to 10·7 per cent in *Parwa* soil and from 6·6 to 8·0 per cent in *Rakar* soil. The values are generally decreasing with the increase of the particle size and ultimately come down in the coarse sand fraction to about 0·42 to 1·17 per cent in *Kabar* soil, 0·11 to 0·34 per cent is *Parwa* soil and 0·06 to 2·97 per cent in *Rakar* soil.

From previous observations it has been seen that the accumulation of the total iron in the finer size-fractions is due to relatively greater weathering of iron-containing minerals as compared to the non-iron ones. It has also been shown that where conditions favourable for the oxidation of iron exist, as in the *Rakar* soil, the free iron on deposition as a result of weathering loses its mobility and gets into the concretion forms. This produces the characteristic *murrum* horizon in the profile. But in soil systems where they are not subject to so rapid oxidation, the free iron, on removal from the rock particles, gets fixed into the lattice and becomes lattice iron. This assumption is borne out by the fact that the top layers of the *Kabar* and *Parwa* coarse and fine clays are comparatively richer in lattice iron than the corresponding layers of the *Rakar* soil. The behaviour of the *murrum* horizon in the *Rakar* soil in showing richness in lattice iron shows that along with concretion formation in that soil there is also a concomitant tendency of lattice iron formation presumably when this horizon remains wet during the rainy season.

Contribution of size-fractions to soils

Altogether the data given in Table III corroborate in general the findings reported earlier. Coarse and fine clays contribute towards the total iron content of the soil to the extent of 60 to 70 per cent, the coarse and fine sand contributing not more than 20-25 per cent. This behaviour is not observed in the last layer of the *Rakar* profile where the sands contain about 63 per cent of total iron and clays only 24 per cent. This is due to secondary concretion formation which is brought about as a result of highly oxidative regime present throughout in that profile, especially at the *murrum* layer.

The two clay fractions also contain the highest quantities of free iron. Evidently, the weathering process produces free iron in the finest particles and that the amount of free iron present in the sand particles is due to secondary aggregation. That this secondary aggregation is more pronounced in the bottom layers of the *Kabar* and *Parwa* soils points to the fact that the tendency of *murrum* formation is present in all the three profiles, but the concretionary *murrum* layers only form in the *Rakar* soil where condition favourable to its formation exists in comparison to the other two soils.

TABLE III. IRON CONTENT IN DIFFERENT MECHANICAL FRACTIONS: CONTRIBUTION OF SIZE-FRACTIONS TO SOIL

Lab. No.	Coarse sand			Fine sand			Silt			Coarse clay			Fine clay			Values present in soil		
	Total	Lattice	Free	Total	Lattice	Free	Total	Lattice	Free	Total	Lattice	Free	Total	Lattice	Free	Total	Lattice	Free
R-2292	0·140	0·034	0·106	0·409	0·337	0·072	0·340	0·269	0·071	0·541	0·379	0·162	0·701	0·484	0·217	2·131	1·503	0·628
	6·57	2·260	16·88	19·19	22·42	11·47	15·95	17·90	11·31	25·38	25·22	25·80	32·89	32·20	34·55			
2293	0·256	0·163	0·093	0·283	0·358	0·051	0·605	0·371	0·234	1·106	0·616	0·490	1·496	0·914	0·582	3·746	2·422	1·450
	6.83	6·73	6·41	7·55	14·78	3·52	16·15	15·32	16·14	29·52	25·43	33·79	39·93	37·74	40·14			
2294	2·460	1·948	0·512	0·961	0·196	0·087	0·671	0·456	0·215	0·690	0·505	0·185	0·626	0·452	0·174	5·408	3·557	1·173
	45·48	54·77	43·65	17·77	5·51	7·42	12·41	12·82	18·33	12·75	14·20	15·77	11·57	12·71	14·83			
P-2286	0·121	0·039	0·080	0·436	0·371	0·065	0·470	0·399	0·071	1·031	0·740	0·291	1·157	0·950	0·207	3·215	2·499	0·714
	3·76	1·56	11·20	13·56	14·85	9·10	14·62	15·97	9·94	32·07	29·61	40·76	35·98	38·02	28·99			
2287	0·808	0·025	0·055	0·360	0·312	0·048	0·460	0·436	0·024	1·894	1·693	0·201	2·221	1·980	0·241	5·743	4·446	0·569
	14·07	0·56	9·67	6·27	7·02	8·44	8·01	9·81	4·22	32·97	38·08	35·33	38·67	44·53	42·36			
2288	0·125	0·065	0·059	0·372	0·321	0·051	0·658	0·561	0·097	1·686	1·560	0·126	1·915	1·727	0·188	4·756	4·234	0·521
	2·63	1·54	11·32	7·82	7·58	9·79	13·83	13·25	18·62	35·44	36·84	24·18	40·26	40·79	36·08			
K-2282	0·069	0·031	0·039	0·402	0·340	0·062	1·149	0·999	0·150	2·079	1·601	0·478	1·892	1·717	0·175	5·591	4·688	0·904
	1·23	0·66	4·31	7·19	7·25	6·86	20·25	21·31	16·59	37·18	34·15	52·88	33·84	36·63	19·36			
2283	0·116	0·071	0·045	0·415	0·350	0·065	1·215	1·094	0·121	2·254	1·800	0·454	2·228	1·990	0·238	6·228	5·305	0·923
	1·86	1·34	4·88	6·66	6·60	7·04	19·51	20·62	13·11	36·19	33·93	49·19	35·77	37·51	25·79			
2284	0·129	0·082	0·058	0·662	0·551	0·101	1·250	1·237	0·013	2·122	1·753	0·369	1·552	1·439	0·133	5·715	5·062	0·654
	2·26	1·62	8·87	11·58	10·89	15·44	21·87	24·44	1·99	37·13	34·63	56·42	27·16	28·43	17·28			
2285	0·414	0·277	0·137	0·844	0·711	0·133	0·719	0·706	0·013	1·300	1·170	0·130	1·200	1·089	0·111	4·477	3·953	0·524
	9·25	7·01	26·15	18·85	17·99	25·38	16·06	17·86	2·48	29·04	29·60	24·81	26·80	27·55	21·18			

N.B.—Second horizontal line under each soil gives per cent contribution of the forms of iron to the total soil.

The lattice iron contents of the three profiles exhibit the same tendency as the other two forms of iron and show that lattice formation can take place more in the fine fractions of the soil and under conditions where the soil is subject to greater moisture regime. Thus the lattice iron content in the finer particle is more in the case of *Kabar* and *Parwa* soils than in the *Rakar*, but in sands this tendency is reversed as a result of the presence of undecomposed rock particles which are rich in lattice bound iron.

Movement of magnesium in the profile

The magnesium contents of the different size-fractions of the three soils and the contribution which these fractions make in respect to this ingredient to the soil, are given in Table IV.

TABLE IV. MAGNESIUM CONTENT IN DIFFERENT MECHANICAL FRACTIONS: CONTRIBUTION OF SIZE-FRACTIONS TO SOIL

Lab. No.	Coarse sand	Fine sand	Silt	Coarse clay	Fine clay	Values present in soil
R—2,292	0·280	0·084	0·089	0·149	0·135	0·737
	(37·99)	(11·40)	(12·07)	(20·21)	(18·31)	
2,293	0·186	0·061	0·112	0·221	0·266	0·846
	(21·98)	(7·21)	(13·23)	(26·12)	(31·44)	
2,294	0·905	0·145	0·124	0·177	0·148	1·499
	(60·37)	(9·67)	(8·27)	(11·81)	(9·87)	
P—2,286	0·149	0·188	0·118	0·206	0·493	1·154
	(12·91)	(16·29)	(10·22)	(17·85)	(42·72)	
2,287	0·088	0·084	0·067	0·245	0·415	0·899
	(9·75)	(9·34)	(7·45)	(27·25)	(46·16)	
2,288	0·073	0·100	0·164	0·379	0·465	1·181
	(6·18)	(8·46)	(13·88)	(32·09)	(39·37)	
K—2,282	0·048	0·088	0·250	0·416	0·596	1·398
	(3·43)	(6·29)	(17·88)	(29·75)	(42·63)	
2,283	0·039	0·105	0·219	0·432	1·114	1·909
	(2·04)	(5·50)	(11·47)	(22·62)	(58·35)	
2,284	0·052	0·138	0·375	0·484	0·679	1·728
	(3·01)	(7·98)	(21·70)	(28·01)	(39·29)	
2,285	0·270	0·166	0·218	0·332	0·644	1·630
	(16·56)	(10·18)	(13·37)	(20·36)	(39·50)	

N.B.—Figures in parenthesis give percentages contribution of the magnesium to the total soil.

A scrutiny of the data indicates a gradual decrease in the magnesium content of the fraction with the increase in the particle size up to the fine sand only. The content of magnesium in the coarse sand particle is more than that in the fine sand fraction. This behaviour is inexplainable. The finest soil particles of the *Kabar* soil are the richest in the magnesium content. As with iron, it appears that with the increase in the development of the soil there is concentration of magnesium and where conditions of natural drainage are poor there is greater accumulation of magnesium.

DISCUSSION

Barshad (1955), while describing the relative stability of the minerals to weathering, has stated that the degree of weathering is related to the degree of basicity of the minerals. The more basic the mineral the more prone it is to weathering. After feldspars, the ferromagnesium minerals are the most prominent constituents of the igneous rocks. They occur widely in basic igneous rocks, granites, and metamorphic gneisses. The parent materials of the Bundelkhand soils are composed of the basic igneous rocks, granites and gneisses. Since the ferromagnesians are the basic minerals they are classed in the easily weathered group and have comparatively less stability. Under condition of high temperature they become still more liable to weathering. Besides, the presence of ferrous iron in them, which on oxidation greatly reduces the general structural stability of the lattice, makes them still unstable. On oxidation, ferrous iron becomes ferric and some other cation must leave the structure to maintain the electrostatic neutrality status of the lattice. Such a situation leaves empty spaces in the lattice which makes the entire structure to collapse. The ferrous-containing minerals are, therefore, first to decompose in weathering.

The soil-forming reactions that affect the iron content in the profile exhibiting different stages of soil genesis in an area could consist, in the first stage, of the release of iron from the primary minerals which on such release moves from the surface to the subsoil by water percolation. A part of this iron could recombine with silica and alumina to form secondary minerals and a part may form iron concretion. The capacity to form secondary minerals and iron concretions depends on certain environmental conditions. The formation of secondary clay minerals in the soil profile is dependent on a large number of factors. Some of these are the *p*H of the medium, the degree of leaching and the presence or absence of chealating substances. Under excessive leaching, specially for soils of high-lying areas, the silica obtained from weathering may be completely removed from the site of reaction thus unable to form secondary minerals as in the *Rakar* soil. But under restricted leaching a large proportion of silica may also remain in site to combine with iron for formation of clay mineral as in the *Parwa* and *Kabar* soils. This formation is helped in the presence of an alkaline medium since the presence of basic cations, like calcium and magnesium, exert protective effect on such formation. The restricted drainage, better moisture regime and richness in calcium and magnesium of the *Kabar* and *Parwa* soils are, therefore, some of the causative factors for production of such type of clay minerals.

When the above mentioned conditions favourable for the formation of secondary iron minerals do not exist the iron released due to weathering forms hydrated oxides

and under highly leached and oxidative conditions coalesce together to form iron concretions. Such conditions do exist in the coarse textural *Rakar* soil where the *murrum* horizon is the culmination of such a process. The recognised groups of iron containing hydrated oxides are limonite, turgite, goethite and haemetite. These are known to exist in varying amounts in the soil as scales, coatings or concretions, especially in the sand and silt size particles which are called by the general name of *murrum* in the Indian red soils.

In regard to the contribution of magnesium from the different size-fractions to the whole soils clays, both coarse and fine, contribute the maximum and sands, both coarse and fine, the minimum in the case of the poorest drained member, viz.,the *Kabar* soil, but this behaviour is reversed in the case of the excessively drained *Rakar* soil. The intermediate member, *Parwa* soil, shows a behaviour in the mid-way between the two. Similar observations were made in the case of iron distributions. It appears, therefore, that in the pedogenesis of these soils, iron and magnesium, which are the two prominent components of the ferromagnesian minerals, behave similarly, and a study of their movement in the soil profiles *inter se* profiles of other areas can give valuable information in regard to the soil-forming processes operating in such tracts.

TABLE V. MOLECULAR RATIOS OF MgO/Fe_2O_3 IN SOIL

Laboratory number	In fine sand		In fine clay	
	Ratio on total iron	Ratio on lattice iron	Ratio on total iron	Ratio on lattice iron
R—2,292	0·82	1·00	0·77	1·60
2,293	0·85	1·04	0·71	1·97
2,294	0·60	0·63	0·95	1·46
P—2,286	1·09	1·28	1·35	2·49
2,287	0·91	1·07	0·76	1·17
2,288	1·07	1·24	0·97	1·47
K—2,282	0·86	1·01	1·26	2·76
2,283	1·01	1·20	2·00	3·03
2,284	0·83	0·99	1·75	2·21
2,285	0·78	0·93	2·15	2·86

In view of the above, a comparison of the molecular magnesia-iron ratio (Table V) in the clay fractions of the soils representing the weathered portion as compared to that in the fine sand fractions representing the unweathered may lend itself to be a guide for judging the degree of soil formation in much the same way as the silica-alumina ratio in the lateritic zone. Swenson and Riecken (1955) are also of the same view and their work on the movement of iron in the development of loess-derived soils of the U.S.A.

supports the hypothesis built in the present paper. They call the process of the weathering of ferromagnesian minerals as "argisolization" in conformity with the terminology of soil-forming processes like podsolization and laterization.

SUMMARY

A quantitative study of the movement of iron and magnesium in the three soil profiles of the Bundelkhand soils in Uttar Pradesh and their relative proportions in the different size-fractions of the soils has been made. It has been suggested that under the climatic and other conditions present in the area the ferromagnesian minerals are the first to decompose and the relative content and form of these elements in the soil give to them the typical characters that make them genetically different in the catena.

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REFERENCES

Agarwal, R. R. and Mukerji, P. 1946. *Indian J. agric. Sci.* **16**: 483.
———— and Mehrotra, C. L. 1952. *Soil Survey and Soil Work, U.P.* **2**.
Barshad, I. 1955. *Chemistry of the Soil.* Reinhold Pub. Co.
Hoore, J. L. D., Fripiat, J. J. and Gastuche, M. C. 1954. *Proc. Second Inter. Afr. Soils Conf.* **1**: 257.
Mackenzie, R. C. 1954. *J. Soil. Sci.* **5**: 167.
Piper, C. S. 1950. *Soil and Plant Analysis.* The University of Adelaide.
Robinson, G. W. 1933. *Imp. Bur. Soil Sci. Tech. Comm.* 26.
Scott, R. O. 1941. *Analysts* **66**: 142.
Swenson, R. M. and Riecken, F. F. 1955. *Soil Sci.* **79**: 177.

EFFECT OF SUPPLEMENTING PHOSPHATE AND POTASH WITH NITROGEN ON THE YIELD OF WATERLOGGED RICE

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Manuring of rice in India has shown a universal and substantial response of nitrogen, sporadic and inconsistent response of phosphate and almost none of potash to yield (Sethi *et al.*, 1952; Ghose *et al.*, 1956). Recent claims of significant phosphate and potash responses to rice production in cultivators' fields (Mukherjee, 1955a, b) tended to undervalue the results of experimental stations and required reassessment in building up a confident manurial schedule for rice cultivation. However, the investigations of Basak *et al.*, conducted for about ten years, have shown quite high and almost comparable magnitude of response of nitrogenous manuring and fertilization to rice production in farmers' fields (Basak *et al.*, 1957; Basak and Klemme, 1959) as well as experimental stations (Basak, 1956).

The present study was undertaken to (a) test the response of phosphate and potash, in the presence of nitrogen, to rice yields in farmers' fields; (b) confirm the influences of soil types, moisture conditions and cultural practices on the efficiency of utilisation of soil and applied nitrogen to rice production; and incidentally, (c) study the biological role of gastropods (*Mollusca*) in maintenance of stable fertility of waterlogged rice soils.

MATERIAL AND METHODS

Two parallel series of 25 trials were conducted in farmers' fields in different soil climatic zones of West Bengal during the 1958 paddy season. N was applied @ 30 lb. per acre, as ammonium sulphate in one series and compost in another. Superphosphate @ 20 lb. P_2O_5 per acre was superimposed on N, and muriate of potash @ 20 lb. K_2O per acre on NP combination in both series with respective checks. The treatments were applied during puddling of soils prior to transplantation of seedlings. Same rice variety was put under the twin trials at any given centre and 18 local *indica* varieties were covered by these trials. Crop was rainfed and grown under local methods of cultivation. Yields of grain and straw, harvested from subplots of one-twelfth acre during mid-Nov. to mid-Dec., are given in Tables I and II. The data were statistically analysed, as in the randomized block lay-out, considering centres as blocks.

After harvest, distribution of root systems in soil profiles (check plots) was studied *in situ*. In the course of such studies, bodies of animals (some living and many dead), identified as gastropods (mainly *Pila globosa*, *Spirorbis* sp.), were found to occur in all trial plots irrespective of soil types and land situations. The gastropods seemed to have travelled down in certain profiles to a depth of about 60 cm. below surface, the density of their distribution decreasing progressively with depth. The chemical composition of

some of these was determined (Table IV), and the role of these animal bodies in the maintenance of fertility of waterlogged rice soils has been discussed.

OBSERVATIONS

A. *Response of nitrogen to yield:* Response of nitrogen to yield was positive, consistent, and highly significant. 30 lb. N per acre, as organic manure (compost) or ammonium sulphate, gave increased grain yields of 44·4 and 46·8 per cent, respectively, over unmanured checks (Table I). The results were comparable to those obtained in earlier trials (Basak and Klemme, 1959) and were of great practical importance in boosting rice production in underdeveloped countries where industrial production of fixed nitrogen was far below the requirement and the purchasing power of the farmers inordinately low.

TABLE I. RESPONSE OF NPK FERTILIZATION TO GRAIN YIELD

Source of nitrogen	Treatment	Yield of grain in md. per acre (1 md. = 82·29 lb.)			Per cent increase over check
		Gangetic alluvium	Lateritic soil	Mean	
Compost	Check	18·69	26·47	20·55	..
	N	27·19	37·53	29·67	44·4
	NP	24·64	39·64	28·24	37·4
	NPK	25·76	35·93	28·20	37·2
Ammonium sulphate	Check	17·91	22·75	19·07	..
	N	25·02	37·64	28·00	46·8
	NP	25·01	38·00	28·12	47·4
	NPK	23·96	38·62	27·48	44·1
Mean yield under treatments (lb./acre)	Check	1,506	2,025	1,630	..
	N	2,148	3,092	2,372	45·5
Increase yield in lb. per lb. of applied N		21·4	35·6	24·7	
Analysis of variance	'F' test	Significant at 1% level	Significant at 1% level	Significant at 1% level	'T' test between 2 soil types: highly significant
	$S.E._m$=	± 1·05	± 3·23	± 1·12	
	C.D.= at 1 % level	± 2·75	± 8·72	± 3·07	

N: 30 lb. N/acre P: 20 lb. P_2O_5 /acre K: 20 lb. K_2O/acre.

Planting time appeared to have a notable effect on rice production, particularly under applied nitrogenous fertilization. The interrelation between planting time and grain yield (Fig. 1) at the level of 0 and 30 lb. N per acre over a planting season from mid-July to mid-September has been shown earlier (Basak and Klemme, 1959). The anticipated grain yields of 50 trials, on the basis of average planting date of

August 18, were accordingly estimated at 20·4 and 29·0 md. at 0 and 30 lb. N per acre, while the actual yields were reckoned at 19·8 and 28·8 md., respectively. The value of yield-planting time curves in predicting grain production of a season-fixed rice crop in a rainfed tract on the basis of planting time was, thus, apparent and the benefit of correct planting schedule in securing optimum production was confirmed.

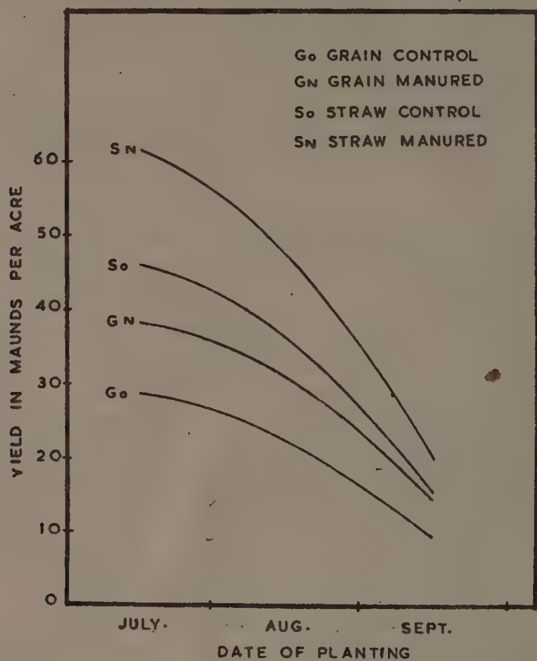

FIG 1.

B. *Influence of soil types, moisture conditions and cultural practices on absorption and assimilation of nitrogen:* The lateritic soils seemed to possess a significantly superior grain-producing capability than heavier alluviums, in spite of their inferior fertility status. Gangetic alluvium gave an average production of 1,506 lb. grain per acre in 38 trials, while lateritic soils gave 2,025 lb. in 12 trials—an increase of 34·5 per cent (Table I). In the previous years' trials, the corresponding grain production in the two soil types was 1,739 lb. and 2,386 lb., respectively (Basak and Klemme, 1959). Pooled average of 71 trials in Gangetic alluvium was, therefore, 1,611 pounds and, of 25 trials in lateritic soil 2,211 pounds grain per acre—an increase of 37·2 per cent over the former group.

The yield response of applied nitrogen was also significantly higher in lateritic soils than in alluviums. While the latter gave an additional production of 21·4 lb. grain per pound of added nitrogen, the former gave 35·6 lb. (Table I). Corresponding grain production in respective soil types in previous trials was 16·1 lb. and 34·9 lb. per pound of added N (Basak and Klemme, 1959).

Differential performance of the soil types would seem to indicate a difference in their relative capacities of promoting absorption and assimilation of soil and applied nitrogen by the growing plants.

The lateritic soils, in view of their predominantly higher content of sand, coarse sand, boulders, ferruginous and lime concretions and of inordinately lower content of silt and clay than in alluviums, possessed better mechanical facilities for development and distribution of root systems in the soil profiles. While rhizosphere of the fully developed plants was found to extend down in the profiles from 10 to 20 cm. in heavier alluviums and more in lighter ones, that in lateritic soils, far more profuse, from 40 to 70 cm. The difference in the volume of rhizosphere of growing plants in respective soil medium could have considerable influence on eventual nutrient absorption. This offered a physico-chemical explanation for apparent lack of correlation between fertility status of surface soils and rice yields (Basak and Klemme, 1959).

It was shown by Sen (1937), Ghosh (1954) and Basak (1957) that shallower submergence at the tillering stage promoted tiller formation while deeper submergence retarded it, and that absorbed nitrogen was preferentially assimilated in increasing tiller number in former case and elongation of preformed tillers in the latter. Heavily terraced lateritic regions possessed conspicuous physical advantages of efficient drainage of received precipitation, while heavy alluvium flat and lowlands were usually susceptible to prolonged deeper submergence. Average number of grain-bearing tillers per plant hill, in the present trials, was 11·9 in the Gangetic alluvium and 13·8 in lateritic soils and grain yield was highly correlated with grain-bearing tillers (unpub. work). Straw-grain ratio was also higher in latsols than in alluviums (Table II). Soil-moisture conditions operating in rice fields had, thus, enormous physiological influence on the regulation of tiller formation and eventual crop yield. Again, larger tiller formation in latsols presented a larger leaf area for photosynthesis and an enhanced metabolic demand for synthesis and lay-out of new proteins at the growing points. Both these physiological processes were conducive to greater nutrient absorption (Truog, 1953).

Cultural practices followed in different soil tracts had also their influence on yield. In many regions in lateritic tracts, well after establishment of seedlings, thin slices of surface soils in inter-row space were turned over by small hand spades and deposited along the plant rows, primarily as a measure of controlling weed growth. Partial relief of adverse hydrostatic pressure at the tillering zones as a result of raising of soil level at the plant hills through this practice ensured physiological benefit of enhanced tiller formation while contriving to hold much of available water at innumerable shallow basins all round the plant hills. This laborious practice was purposely allied to, although somewhat slower and costlier than mechanical weeding by "paddy weeder" in Japan. In heavy alluviums, particularly under flat and low situations, however, much of the physiological benefit of such cultural operation was lost by continued deeper submergence, which itself caused suppression of weed growth.

C. *Response of phosphate:* Application of superphosphate @ 20 lb. P_2O_5 per acre, in conjunction with 30 lb. N of compost or ammonium sulphate, did not give any significant response to grain yield in farmers' fields (Table I). In an earlier series of

replicated experiments at a state experimental station, the same unit of phosphate, when applied in conjunction with a higher unit of N (40 lb. per acre) in different forms of organic and inorganic fertilizers, also failed to record any significant response (Basak, 1956).

TABLE II. RESPONSE OF NPK FERTILIZATION TO STRAW YIELD

Source of nitrogen	Treatments	Yield of straw in md. per acre (1 md.=82·29 lb.)			Per cent increase over check	Straw-grain ratio	
		Gangetic alluvium	Lateritic soil	Mean of soils		Alluvium	Lateritic
Compost	Check	28·82	50·43	34·00	..	1·54	1·90
	N	40·48	60·62	45·32	33·9	1·49	1·62
	NP	38·82	65·66	45·25	33·7	1·58	1·66
	NPK	39·06	56·43	43·23	27·6	1·52	1·57
Ammonium sulphate	Check	27·71	50·78	33·24	..	1·55	2·23
	N	41·02	67·43	47·36	42·3	1·64	1·79
	NP	40·55	65·28	46·48	39·7	1·62	1·72
	NPK	41·84	70·17	48·63	46·1	1·75	1·82
		Straw increase in lateritic soils over alluvium		Per cent	Mean		
Mean	Check	28·25	50·61	78·8		1·54	2·05
	N	40·75	64·03	56·9	64·3	1·56	1·70
	NP	39·69	65·47	64·9		1·60	1·69
	NPK	40·45	63·30	56·5		1·63	1·70
	Analysis of variance	'F' test significant at 1 % level S.E$_m$=±1·86 C.D.=±6·8 at 1% level					

Of the three major nutrients, phosphorus requirement of rice crop was relatively the lowest. A 3,000-lb. rice crop in Cuttack (India) was found to remove 30 lb. P_2O_5 per acre (Ghose *et al.*, 1956), while Beacher (1952) in Arkansas (U.S.A.) referred to removal of only 22 lb. P_2O_5 by a 65-bushel (2,925 lb.) crop. On the other hand, two-million pounds of surface soil were calculated to contain, in terms of available P_2O_5 content of trial soils (Basak and Klemme, 1959), about 78 lb. of this nutrient per acre, which were apparently sufficient to support a rich harvest. Even this available P_2O_5 constituted only 4·3 per cent of the total phosphorus content of these soils (Basak and Klemme, 1959). According to Bhangoo and Smith (1959), one-third to half of total soil phosphorus was present as insoluble iron and aluminium phosphates and one-third to one-fifth as organic phosphorus. Solution of phosphates through reduction of iron and aluminium compounds under anaerobic condition of waterlogged soils rendered a heavy quantum of this nutrient available to the crop. Mineralisation of organic phosphorus, the content of which was positively correlated with total organic matter

and total nitrogen content of soils (Bhangoo and Smith, 1959), further improved the position of available phosphate supply. Predominance of water-soluble phosphate ions ($H_2PO_4^-$) in acid medium ($pH=5{\cdot}2$-$6{\cdot}4$) of waterlogged rice soil and their continuous animation in damp soil (thermal motion) by spontaneous movements of translation which displace them, by successive haphazard bounds, within all the space occupied by the soil water (Barbier, 1959) were favourable conditions for efficient absorption of ions. Notwithstanding a low to medium phosphate content, waterlogged soils were, thus, exceptionally suitable media to support phosphorus nutrition of rice crop.

In rainfed rice cultivation, however, the uncertainty of rainfall and drought very often affected the moisture conditions in rice field and unfavourable moisture conditions interfered with the availability of soil phosphates. Such interference mainly accounted for the inconsistency of response of applied phosphate in rice cultivation. In view of the possibility, rather frequency of such interference with phosphate availability in cropped soils and of the physiological benefit of applied phosphate in water economy of rice plants by way of reduction of the transpiration ratio (Hector, 1928; Ganguli, 1950), phosphatic fertilization was both helpful and necessary in tiding over the adverse effect of drought and consequent depression of phosphate release from soil and also in recompensing the loss of soil phosphates due to crop uptake for maintenance of permanent fertility and stable yield.

D. *Response of potash:* Application of potash, in conjunction with nitrogen (as compost or ammonium sulphate) and phosphate, showed no influence on rice yield (Table I). Average content of exchangeable potassium in two million pounds of surface soils (540 lb./acre; Basak and Klemme, 1959) was presumably enough to support not only an average rice yield in India (1,026 lb. per acre) but even the highest individual yields (4,200 lb./acre) obtained in these trials as to reflect no response of applied potash.

Capability of Indian soils in supply of potassium requirement of rice crop had been universally demonstrated from trials in experimental stations (Sethi *et al.*, 1952; Stewart, 1947). However, Mukherjee (1955b) obtained some evidences of potash response from trials in cultivators' fields in Bihar. An average response of only 176 lb. grain per acre over normally low basal yields was obtained by 40 lb. K_2O, in conjunction with 20-40 lb. N and P_2O_5. The response of 4·4 lb. grain per lb. K_2O was feeble and uneconomic. It was attributed to deficiency of citric-soluble potash in cultivators' field soils. The interpretation seemed inadequate in view of the analytical figures offered (0·004-0·026 per cent C.S. K_2O) because even the lowest ranges of potash values were not likely to be limiting to the level of production obtained. A far richer harvest of 3,000 lb. rice grain per acre did not extract more than 79 lb. K_2O (Ghose *et al.*, 1956). The interpretation seemed even untenable in view of positive potash response obtained (Mukherjee, 1955b) in five out of nine soils containing as much as 0·01 per cent C.S. K_2O, which amounted to 200 lb. C.S. K_2O per acre. What seemed to have been overlooked was the soil moisture condition in the field during crop growth, because this largely determined the absorption of potassium by plants and its replenishment in clay complex from solution of soil minerals. From a study of 20-year data on continuous crop rotation experiments at Aberdeen, Cowie (1945) found that regression coefficients of yield on rainfall were negative and consistently higher in value with oats, barley, etc., under NP treatment as compared to NPK treatment.

Potassic fertilizers were, thus, more effective in dry seasons than in wet ones, partly due to the harmful effect of drought on K-starved plants—the symptoms of potassium deficiency appearing early and being more severe in dry seasons, but mainly due to the beneficial effect of rainfall in promoting the absorption of potassium from the soil. Addition of potash also endowed the plants with water-economizing power (Cowie, 1951).

Actual rainfall data (Table III) in areas and years of Mukherjee's rainfed trials left no doubt that moisture supply was inadequate during the 'critical' stages of flowering and seed-setting in October with repercussions on seed development in November. This would seem to explain the feeble response of applied potash. In such conditions of inadequate rainfall and moisture supply, particularly during critical stages of crop life, potash was of very little value in arresting the overall depression in grain yield which required nothing else but irrigation. Hence, the present view of Indian scientists regarding the general capability of Indian soils in meeting the potash requirement of rice crop would seem to hold good, provided moisture supply was adequate, till a future brought about heavy depletion of potash through continuously heavier rice production under stimulus of massive NP fertilization to eventually reduce the potash status of soils to far below the present one.

TABLE III. MONTHLY RAINFALL DURING GROWING PERIOD OF RICE IN WEST BENGAL AND BIHAR

Region	Year	Monthly average rainfall in inches				Reference
		Aug.	Sept.	Oct.*	Nov.	
17 districts of Bihar[1]	Normal	12·79	8·83	2·64	0·42	Deputy Director-General of Observatories (Climatology and Geophysics), Government of India, Poona.
	5-Year average (1950-54)	11·76	8·40	1·18	0·17	
10 districts of West Bengal[2]	Normal	11·83	8·42	3·87	0·68	Statistical Officer, Govt. of West Bengal, Calcutta.
	1958	9·84	8·75	4·19	0·21	
Requirement of rainfall for optimum production		11·30	11·14	9·29	1·90	Basak, M. N: Proc. Nat. Inst. Sci. India. 23B: 17-34. 1957.

*Flowering: middle to end of Oct.
[1] area of trials of Mukherjee (1955b)
[2] area of present trials

E. *Role of gastropods* (Mollusca) *in maintenance of fertility of waterlogged rice soils:* Extensively wide and plentiful occurrence of gastropods in waterlogged rice fields would seem to suggest for them an important biological role in maintenance of soil fertility. These animals were known to thrive best in moist soils under moderately warm climate, strangely coinciding with agro-climatic conditions favourable for rice culture. Monsoon showers and subsequent flooding of rice fields, which incidentally

brought them to soil surface after a period of hibernation during the winter and dry summer months, promoted vigorous growth of weeds, mosses, algae, etc., to provide ready food materials for these 'soil scavengers'. These conditions were also congenial to their profuse breeding and development. With the approach of winter, towards the end of the cropping season, they again go for hibernation. Many seem to die during hibernation and most of them including living ones occurring within the plough-sole undergo disintegration during tillage operation. Disintegration of the shells, which contained 57 per cent calcium oxide, provided a concentrated source of supply of this element to soil. Their growth and development during progress of the cropping season also offered a biological contrivance to arrest heavy percolative loss of reserve calcium from topsoils through solution (mainly as bicarbonate) under flooded condition. The decomposition of protein matter enriched the soil in concentrated supply of easily available plant nutrients (Table IV) and promoted further microbial growth. Stimulated microbial activities could set up chain reactions in accelerating the mineralisation of soil organic matter and the weathering of soil minerals to augment further release of locked-up nutrients.

TABLE IV. COMPOSITION OF GASTROPODS (*MOLLUSCA*) FOUND IN WATERLOGGED RICE FIELDS

	Per cent composition (oven-dry basis)			
	Total N	P_2O_5	K_2O	CaO
Body	7·64	1·50	0·38	5·0
Shell	0·03	0·07	0·10	57·0

SUMMARY

Two parallel series of 25 trials were conducted on waterlogged rice crop in farmers' fields with the use of 30 lb. N per acre in the form of compost and ammonium sulphate. Applied N boosted grain yields to 45 per cent over unmanured checks, while the form of N reflected no significant difference in the magnitude of response.

Absorption and assimilation of soil and applied N were found to depend on soil types, moisture conditions in the field during crop growth and cultural practices followed.

Superimposition of superphosphate @ 20 lb. P_2O_5 per acre on N did not influence yield. This seemed to be partly due to a relatively low phosphorus requirement of rice crop as compared to its content in average soils but largely due to the chemical changes brought about by waterlogging in making available to the crop a heavy quantum of soil phosphates by way of solution of immobilised iron and aluminium compounds through reduction under anaerobic conditions.

Supplementation of muriate of potash @ 20 lb. K_2O per acre on NP combination also did not influence the rice yield. This was mainly due to the higher content of exchangeable potassium in average soils than the potassium requirement of rice crop

and partly to the ideal suitability of moisture conditions in waterlogged soils for replenishment of exchangeable potassium in the clay complex from solution of potassic soil minerals.

Plentiful occurrence of gastropods (*Mollusca*) in and their characteristic biological association with waterlogged rice soils indicated their natural contribution to maintenance of stable fertility of such soils.

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REFERENCES

Barbier, G. 1959. Definition of "Available Phosphorus" in Soil. *Fertilité* **6**: 3-12.

Basak, M. N. 1956. Effect of Bulky Organic Manures on the Nutrition of Rice. *J. Indian Soc. Soil Sci.* **4**: 95-103.

———— 1957. Effect of Rainfall on the Yield of Rice and Evaluation of Water Requirement. *Proc. Nat. Inst. Sci. India* **23**B: 17-34.

————, Dutt, T. and Nag, D. K. 1957. Effect of Bulky Organic Manures on the Nutrition of Rice. II. Effect of Mixed Forms of Nitrogen. *J. Indian Soc. Soil Sci.* **5**: 55-63.

———— and Klemme, A. W. 1959. Effects of Manurial Treatments and Times of Planting on Rice Production in Different Soil Types in West Bengal. *Agron. J.* **51**: 565-68.

Beacher, R. L. 1952. Rice Fertilization. *Arkansas agr. expt. Sta. Bull.* 522. Fayetteville, Arkansas.

Bhangoo, M. S. and Smith, F. W. 1959. Characterization of Nutrient Supplies in certain Kansas Soils. *Indian J. Agron.* **3**: 182-93.

Cowie, G. A. 1945. Study of the Effects of Fertilizers and Rainfall on the Yields of Crops Grown in Rotation. *J. agric. Sci.* **35**: 197-206.

———— 1951. *Potash, its Production and Place in Crop Nutrition.* Edward Arnold & Co., London.

Ganguli, P. M. 1950. Rice in Assam. *Paddy Ser. Bull.* 6. Assam Govt. Press, Shillong.

Ghose, R. L. M., Ghatge, M. B. and Subrahmanyan, V. 1956. *Rice in India.* Indian Council of Agricultural Research, New Delhi.

Ghosh, B. N. 1954. Studies on the Physiology of Rice. VII. Effect of Varying Water Levels on Growth of Rice in Relation to Nitrogen Absorption. *Proc. Nat. Inst. Sci. India* **20**B: 371-87.

Hector, G. P. 1928. *Transpiration of Rice. Ann. Rpt. Dept. Agric., Bengal.* Bengal Secretariat Book Depot., Calcutta.

Mukherjee, H. N. 1955a. *Rpts. on the Experiments on Cultivators' Fields in Bihar* (Mimeograph).

———— 1955b. *Potash Response in "Supposed" Unresponsive Soils Determined by a New Technique of Experiments on Cultivators' Fields.* KALI SYMPOSIUM.

Sen, P. K. 1937. Studies in the Water Relations of Rice. Effect of Watering on the Rate of Growth and Yield of Four Varieties of Rice. *Indian J. agric. Sci.*, **7**: 89-117.

Sethi, R. L., Ramiah, K. and Abraham, T. P. 1952. Manuring of Rice in India. *Indian Coun. agric. Res. Bull.* 38.

Stewart, A. B. 1947. *Rpt. Soil Fertility Investigations in India with Special Reference to Manuring.* Govt. of India Press.

Truog, E. 1953. *Mineral Nutrition of Plants.* The University of Wisconsin Press, Wisconsin.

STUDIES ON TILLAGE

IX. EFFECT OF VARIATION IN DEPTH OF CULTIVATION WITH FERTILIZER DOSES AND THEIR MODE OF APPLICATION ON THE YIELD OF POTATO

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With the growing pressure of ever-increasing population, the soils in this country have been exploited so hard that low yields have become the rule rather than the exception. Food shortage is still a dire problem and the area under principal food grains cannot be increased any further without sacrificing the industrial crops. This is neither desirable nor feasible. The Famine Enquiry Commission, in its report, recommended the production of such crops which could give a larger return of food energy or calories per unit area than cereals. Potato seemed to be the answer. It has a great potential for higher yields, as is evident from the returns obtained in crop competitions.

In the sphere of production some of the costliest items are tillage and manuring besides seed for potato. Cultivation, unfortunately, has remained an art and in the opinion of Russell (1927) has received less aid from science than any of the farmer's practices. The tendency has been to follow the successful man without analysing the elements of his success. The question of depth to which land should be ploughed for obtaining higher yields is still mooted. To mention a few, Morrow and Gardner (1892) failed to obtain difference in yield due to variation in the depth of ploughing. Russell (1956) obtained half a ton per acre more yield on 40 per cent plots due to deep ploughing and reduced yield by this amount on 20 per cent of the fields. Khan (1957) failed to obtain higher yields of crops due to deep ploughing.

Similarly, different authors advocate different rates of NPK mixtures for potato. Bird (1942) recommended 1,000 lb. of 6-8-8 while Hawkins and Brown (1952) found 90-180 lb. N, 180 lbs. P_2O_5 and 180 lb. K_2O per acre to be suitable for potato. Singh and Mehta (1939) showed that when NPK fertilizers were applied singly or in combination, nitrogen had an outstanding effect on both yield and size of potato. Opinions differ widely on this matter and the experience relates to varying soil climatic conditions. Linked with this is the manner of applying fertilizers about which also agreement has not been reached.

Having the above background in view, an investigation to develop the correct technique for the production of potato under conditions as exemplified by Delhi was started in 1952 at the IARI farm and continued each year for a period of five years. This paper deals with the results obtained during the course of the study.

MATERIAL AND METHODS

The experiment was laid out in a split-plot design with four replications. The 24 treatment combinations were divided into six main plots for ploughing and application of fertilizer treatment and four subplots for the fertilizer ratio. The details of treatments are given below.

Treatments

(a) *Cultivation*

C_1—ploughing 9 to 10 in. deep with tractor implements.

C_2—Ploughing 5 in. deep with bullock implements (soil-inverting plough followed by the local country plough).

C_3—ploughing 5 in. deep with the local country plough.

(b) *Application of fertilizers*

P— placed 2 in. below the seed and 2 in. on either side.

T— Topdressed.

(c) *Fertilizer ratios*

F_0— Nitrogen at 120 lb. per acre (control)

F_1— Fertilizer ratio (NPK) in lb. per acre ... 80 : 80 : 40

F_2— ,, ,, ,, ... 120 : 80 : 40

F_3— ,, ,, ,, ... 160 : 80 : 40

In addition to fertilizers, a basal dose of farmyard manure or green manure amounting to an average quantity of 70 pounds nitrogen per acre was given equally to all the treatments.

The variety used for the experiment was Darjeeling Red Round (DRR). Certified seed was obtained from the Director, CPRI, Patna, and kept healthy for subsequent sowings under the supervision of IARI staff.

Soil

The experimental plot had a well-drained and sandy loam soil of moderate fertility and the following constituents (Table I).

TABLE I. CONSTITUENTS EXPRESSED AS PERCENTAGE ON OVEN DRY BASIS

Constituents	Profile 0″–6″	Depth 6″–12″
I. Mechanical composition		
1. coarse sand	1·00	0·76
2. fine sand	75·40	76·90
3. silt	10·50	7·75
4. clay	12·75	15·50
II. Chemical composition		
1. Organic nitrogen	0·040	0·039
2. Total phosphoric acid	0·210	0·240
3. Available phosphoric acid	0·023	0·019
4. Total potash	0·300	0·410
5. *p*H	7·9	7·9

Soil tilth: On an average, three to four cultivations with tractor implements (C_1) and about six with bullock implements (C_2 and C_3), depending upon the season, were given each year. The effect of tillage treatments on soil tilth was also studied.

The percentage of soil aggregates below 7 mm. on dry sieving was found to be 42·1, 28·0 and 34·5 in C_1, C_2 and C_3 treatments, respectively. But the proportion of aggregates of the size distribution of 7 mm. and above were the highest in C_2 followed by C_3 and C_1. The percentage of water stable aggregates of the size 3 to 0·5 mm. was 1·85, 2·36 and 2·56 mm., respectively, for C_1, C_2 and C_3 treatments.

The determination of single value physical constants showed the pore-space percentages as 47·3, 48·46 and 48·04 for C_1, C_2 and C_3 treatments, respectively. The moisture-holding capacity was found to be 31·55 32·73 and 32·63 per cent, respectively, for the same treatments. The percentage of expansion by volume was 12·89 for C_1, 13·18 for C_2 and 12·66 for C_3 treatment.

OBSERVATIONS

As the experiment was located at the same place for all the years under study, the data were pooled in order to get a correct assessment of the work after eliminating the seasonal variations. The year-to-year response was naturally affected to a considerable extent by the seasonal fluctuations. The serial analysis of data is summarised in Table II-VIII.

TABLE II. THE EFFECT OF DEPTH OF CULTIVATION ON THE YIELD OF TUBERS (md. per acre)

Treatments	Years					Average (1952-53 to 1956–57)
	Y_1	Y_2	Y_3	Y_4	Y_5	
C_1	192·36	295·53	275·32	289·23	284·64	267·42
C_2	179·98	284·26	289·85	360·83	272·57	277·50
C_3	181·18	268·99	277·39	319·25	278·15	264·99
Average	184·51	282·93	280·86	323·11	278·46	..
'F' test	Not sig.	sig.	Not sig.	sig.	Not sig.	..
S.E_m.±	5·51	5·53	6·77	11·47	7·37	..
C.D. 5%	..	18·71	..	34·54	..	..

Years:	S.E_m.	± 4·88	Cultivation	
	C.D. (5%)	13·58	'F' test	Not sig.
	'F' test	significant	S.E_m. ±	4·08

The yearly variations in the general trend of yield, may, perhaps, be explained thus:

The first year besides being the initial year of study had also a little effect of late blight on the crop as a whole. The second year was normal. In the third year,

unfortunately, the winter was severe with two very severe frosty nights during the growing season. The fourth year had a very favourable season for crop growth. The severe frosts as experienced in the previous season were absent. In the concluding year, unfortunately, the seasonal conditions were abnormal. The rainfall received during October, the month of planting the crop, was 10·04 inches which interfered with the normal preparation of seed-bed. Moreover, the month of February was abnormally cold accompanied by frosty nights.

It may, however, be remarked that the effect of season was uniform over all the treatments without particularly favouring any one of them.

The differences between the three tillage treatments are not marked, showing that the standard of tilth produced is almost the same under each treatment. The yields obtained are generally satisfactory.

TABLE III. THE EFFECT OF FERTILIZER RATIOS ON THE YIELD OF TUBERS (yield in md. per acre)

Treatments	Years					Average (5 years)
	Y_1	Y_2	Y_3	Y_4	Y_5	
F_0	144·25	252·61	258·37	296·78	238·42	238·08
F_1	193·59	288·13	280·35	320·97	271·00	270·80
F_2	202·38	289·33	289·10	328·86	293·34	280·60
F_3	197·82	301·62	295·58	345·79	311·04	290·36
'F' test	sig.	sig.	sig.	sig.	sig.	sig.
S.E$_m$. ±	5·24	6·59	5·94	7·75	6·93	3·36
C.D. (5%)	14·84	18·71	16·84	21·98	20·53	9·52

It is seen from Table III that differences in treatments, both for individual years and the period as a whole, are significant. The effect of phosphate and potash in combination with nitrogen is not only pronounced in the serial analysis, but has invariably produced higher yields over N alone. The necessity of having complete minerals in the manurial schedule for potato is obvious.

TABLE IV. THE EFFECT OF PLACEMENT OF FERTILIZERS ON THE YIELD OF TUBERS (yield in md. per acre)

Treatment	Years					Average (5 years)
	Y_1	Y_2	Y_3	Y_4	Y_5	
P	187·15	272·09	271·83	305·85	276·19	262·64
T	181·86	293·76	289·87	340·35	280·71	277·33
'F' test	Not sig.	sig.	sig.	sig.	Not sig.	sig.
S.E$_m$. ±	4·50	4·51	5·53	9·37	6·02	3·33
C.D. (5%)	..	13·52	16·65	28·21	..	10·05

The placement method of fertilizer application was not found superior to the conventional method of broadcasting. This may, perhaps, be due to the practice followed in the cultivation of potato. The crop is being regularly earthed, and in so doing the topdressed fertilizer is eventually placed on the ridges near the seed. The comparison, therefore, essentially becomes between the two methods of placement. As would appear from the serial analysis in Table IV, the broadcast application has given a significantly higher yield over placement.

TABLE V. EFFECT OF DOSE × CULTIVATION ON THE YIELD OF TUBERS (md. per acre)

Treatments	F_0	F_1	F_2	F_3
C_1	238·07	265·58	278·47	287·55
C_2	242·65	273·70	283·90	309·74
C_3	233·55	273·14	279·45	273·82

S.E$_m$. ± 5·81

It is evident from Table V that the yields shot up considerably even under a lower level of nitrogen when phosphate and potash were mixed in the dose. The effect was pronounced in all the tillage treatments.

TABLE VI. EFFECT OF DOSE × METHOD OF APPLICATION ON THE YIELD OF TUBERS (md. per acre)

Treatments	F_0	F_1	F_2	F_3
P.	225·90	263·50	273·65	287·47
T.	250·29	278·13	287·57	293·28

S.E$_m$. ± 4·75

Though the results are not significant yet the differences are indicative. Under all levels of N, topdressing of fertilizer has shown better yield.

TABLE VII. EFFECT OF CULTIVATION × METHOD OF APPLICATION ON THE YIELD OF TUBERS (md. per acre)

Treatments	C_1	C_2	C_3
P.	254·34	269·80	263·74
T.	280·50	285·20	266·24

S.E$_m$. ± 5·78

The trend in Table VII is the same as in the previous one. The topdressed dose has given higher yields than the placed, irrespective of the tillage treatments.

TABLE VIII. THE EFFECT OF TRIPLE INTERACTION ON THE YIELDS OF TUBERS (md. per acre)

Treatments	C_1		C_2		C_3	
	P	T	P	T	P	T
F_0	221·80	254·33	228·59	256·71	227·29	239·80
F_1	246·59	284·58	275·08	272·33	268·83	277·46
F_2	266·15	290·78	274·54	293·26	280·25	278·66
F_3	282·81	292·29	224·60	318·50	278·60	269·04

$SE_m \pm$ 8·22

The trend as shown in the main effects is also evident in the above interactions (Table VIII). The highest yield was obtained with C_2 TN_3 followed by C_2 TN_2.

Though the interactions were not significant, the trends as noticed in the case of main effects were evident and are discussed in each table.

DISCUSSION

The effect of tillage implements in modifying soil properties is well recognised. It is believed that a good structure of soil is key to fertility. The criterion for good structure is generally considered to be the 'aggregation' which should form such a balance between macro- and micro-pores as to allow the passage of air and retention of water in the soil in a way best suited for the growth and development of a crop.

In this study, all the tillage treatments have thoroughly disintegrated the structure as is evident by the small proportion of water-stable aggregates. Similar effect has been observed by several workers including Khan *et al.* (1958), Keen (1933), McIntyre (1955) and Swanson *et al.* (1955). The study of other physical constants such as pore space, water-holding capacity, etc., which are responsible for determining the quality of the soil fabric, revealed that the difference between treatments was not marked.

The small difference in yield between the tillage treatments indicates that cultivation beyond 5″ depth is not necessary. This fact has been confirmed by the results of previous experiments in the series on other crops. Potato being a shallow-rooted crop with a superficial root system is not expected to get much benefit by deep ploughing. Russell and Keen (1938 and 1941) Russell (1950) and Constable and Pollard (1952) also found that deep cultivation for potato is not required.

In regard to the effect of fertilizer doses on the yield of tubers, it was found that the yield increased with the inclusion of phosphate and potash in the mixture. The highest return was obtained when the nitrogen level was raised to the maximum. The differences between F_1 and F_2 as well as F_3 and F_2 treatments were not significant. But all of them were found to be significant over F_0.

The necessity of keeping a favourable balance of nutrients in the soil in order that the metabolic processes of the plant may proceed satisfactorily, has been stressed by numerous workers including Crowther and Yates (1941), Bird (1942), and Smirnov and Pleshkov (1955).

It appears that the increase in the dose of nitrogen beyond 80 lb. has not raised the yields proportionately. This may, perhaps, be due to the unfavourable balance in the treatments. Metsger (1938) also obtained significantly decreased yield with nitrogen alone. Russell and Garner (1941) and Ellison and Jacob (1954) have stressed the need for a previous appraisal of the nitrogen status of the soil for balancing the nutrients to be applied.

Topdressing of fertilizers in these studies has resulted in higher yields of potato than the placement. Efficiency of a particular method of application, according to Truog *et al.* (1925), Demolon (1950) and Wit (1953), depends on such factors as nature of the soil, weather conditions, root system of the plant, nature and dose of the fertilizer and cultural practices. Under the present investigation, the soil was a sandy loam with *p*H 7·9 and offered no possibility of fixation. Moreover, the whole soil impregnated with the topdressed nutrients was gathered around the plants by earthing. The land being irrigated helped to make the delivery of nutrients to plants easier. As the soil was light and the crop shallow-rooted, it is possible that the nutrients placed at the bottom of the furrow were not fully exploited by the crop. Cook (1952) was able to demonstrate through his experiment the efficiency of broadcasting the fertilizer on ridges as compared to band placement. Results reported by Jordan and Sirrine (1910) and Reith (1954) confirm this. It is, therefore, evident that under the soil-plant relationship, as existed in this study, the chances of success for a placed application of fertilizer were not bright.

SUMMARY AND CONCLUSION

The yield of tubers was not affected either by the variation in the depth of cultivation or the inversion of soil. As has been experienced in the case of similar projects, data of which have been published earlier, yields in well-drained soils are not sensitive to variation in the depth of cultivation.

It has been shown that potato responds to balanced nutrition. Nitrogen alone is not conducive to higher yields.

Broadcasting of fertilizers when the crop has to be earthed may prove more effective than the placement method.

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REFERENCES

BIRD, J. J. 1942. Potato growing on the Cumberland plateau. *Tenn. agric. Stn. Bull.:* 181.

CONSTABLE, D. H. and POLLARD, A. G. 1952. Effect on soils and crops of varying depths of cultivation. I. *J. Sci. Food and Agr.* **3**(4): 157-60.

COOK, G. W. 1952. Recent development in fertilizer placement. II. *Food and Agr.* **5**: 429-40.

CROWTHER, E. M. and YATES, F. 1941. The fertilizer requirements of arable crops. *Empire Jour. Exp. Agr.:* 99.

DEMOLON, A. 1950. Placement and granulation of fert. *C.R. Acad. Agr.* **36**: 149-51.

ELLISON, J. H. and JACOB, W. C. 1954. Further studies concerning the incluence of irrigation on the NPK requirements. *Amer. Potato J.* **31**: 141-52.

HAWKINS, A. and BROWN, B. A. 1952. Response of potato to rate and placement of nitrogen. *Proc. Soil Sci. Soc.* **16**: 248-52.

JORDON, W. H. and SIRRINE, F. A. 1910. Potato fertilizers: Methods of application and form of nitrogen. *N.Y. State agric. exp. Stn. Bull.:* 327.

KEEN, B. A. 1933. Experimental method for the study of soil cultivation. *Emp. J. Exp. Agr.* **1**(1): 97-102.

KHAN, A. R., MATHUR, B. P. and MAJUMDAR, A. K. 1958. Studies on tillage. VI. *Indian J. agric.* **3**(1): 28-30.

KHAN, A. R. 1958. Observations on the role of tillage. *Proc. Indian Sci. Congr.* **IV**: 150-51.

McINTYRE, O. S. 1955. Effect of soil studies on wheat germination in red brown earth. *Austr. J. agric. Res.* **6**(6): 797-867.

MORROW, G. E. and GARDNER, F. D. 1892. *Ill. agric. exp. Stn. Bull.* 20.

METSGER, C. H. 1938. Fer. For potato in Colorado in 1937. *Amer. Potato J.* **15**: 252-61.

REITH, J. W. S. 1954. Recent advances in fert. placement I. *J. Sci. Food. Agr.* **5**: 421-28.

RUSSELL, E. W. 1950. How deep to plough. *Farming* **4**(12): 359-62.

———— 1956. Effect of very deep ploughing and subsoiling on crop yield. *J. agric. Sci.* **48**(2): 128-44.

RUSSELL, E. W. and KEEN, B. A. 1938. Studies in soil cultivation. *ibid.* **28**: 212.

———— 1941. Studies in soil cultivation. *ibid.* **31**: 326-46.

RUSSELL, E. J. and GARNER, H. V. 1941. 'The Rothamsted experiment on the manuring of potato. Part I. *emp. J. Exp. agric.* **9**(35): 195-215.

———— 1927. *Rothamsted Conf.* **5**: 5.

SINGH, B. N. and MEHTA, M. L. 1934. Effect of manures on size of potato tubers soil. and *Fer.* **2**(34).

SMIRNOV, P. M. and PLESHKOV, B. P. 1955. Effect of NP and organic matter on utilisation of superphosphate by potatoes. *Sci. Food Agric. Abs.* **7**(7).

SWANSON, C. L. W., HANNA, R. M. and DEROO, H. C. 1955. Effects of excessive cultivation and puddling on conditioner—treated soils in the laboratory. *Soil Sci.* **79**: 15-24.

TRUOG, E. and HARPER, H. J. 1925. Fertilizer Experiment. *Wis. agric. exp. Stn. Bull.* 65.

WIT, C. T. 1953. *Physical Theory on placement of Fertilizer.* Vers. I. Land-boiwk. Guderzock **59**.

REVIEWS

Cockle Park Farm by H. Cecil Pawson. Oxford University Press, London, 1960. Pp. i-xiv, 1-261. Price (in U. K. only) 35s.

In *Cockle Park Farm*, the Oxford University Press presents an account of the extensive and intensive experimentation conducted at the Cockle Park Experimental Station from 1896-1956.

The idea of the establishment of Cockle Park was mooted 100 years back and took its present shape in 1896. For many years, it was known as the Northumberland County Agricultural Experiment Station. The Northumberland County was one of the pioneers in the field of agricultural education. Work at Cockle Park started with the implementation of a programme of research planned by the agricultural administration of this county in about 1891. This programme included courses of 'extension lectures' as well as 'delivery of pioneer lectures in small towns and villages'.

Dr. Somerville, Middleton and Gilchrist were the three great agriculturists who were intimately associated with the development and permanent establishment of Cockle Park. Dr. Somerville was responsible for conducting classical experiments on the growth of trees, some aspects of Palace leas and laying of the backhouse field. Dr. Middleton was a brilliant administrator and was responsible for extending the usefulness of Somerville's experiments. Dr. Gilchrist specialized in research on grassland (Chap. 1). Most of the Cockle Park farm lies about 300 feet above sea level. The variety of soils in and around the Farm is advantageous for experimental work. The Farm represented a poor agricultural holding in its earlier days. However, the normal working hours and the wages for the farm worker were considerably longer and small, respectively, than now. No overtime was paid for. Modern mechanization at the Park started in 1917. Considerable improvement in agricultural produce and livestock is noticed (p. 39). For many years, the main livestock sales consisted of cattle, sheep, hogs and, sometimes, lambs (Chap. 2).

Some pioneering work in the improvement of poor grassland has been undertaken on the Park; and most of the results of the trials conducted have been widely disseminated by means of demonstrations at the Park, lectures at different centres, and through publications. Permanent pastures, with particular reference to their susceptibility to grazing and the effect of manuring, have been maintained. Results of trials conducted on the growth of trees, grazing, pastures, etc., show a marked advance (Chap. 3).

In 1897, a study of the improvement of quality and quantity on the hay crop on laying-term basis was initiated. Except for 1897 to 1906, a complete record of manures applied to the soil has been maintained for 58 years. The increasing quantity of crop affected adversely the quality as shown by crude protein contents, protein digestibility and calculated starch equivalent (Chap. 4).

The origin of work on seed-mixtures and leys at the Park is credited to Gilchrist. Various methods of investigations on seed-mixtures have been discussed. The yield of

various plants under different manures shows considerable variance. Gilchrist tried to evolve simplified seed-mixtures. Considerable importance has been attached to basic slag during the continued growth of various crops.

The animal behaviour studies were initiated in 1949, primarily to determine the value of such records in pasture evaluation study. It was found that the variation in animal behaviour, caused by variation in sward conditions, may be a measure of the energy wasted in consuming the full feed of herbage (Chap. 5).

The rotation experiments were again repeated in 1914 and continued up to 1954. During the post-war years, selective weedicides were used, but it was found that these are not a complete answer to the problem of weed infestation on arable land (Chap. 6).

Root and green crops have been studied with respect to varietal trials and manurial treatments (Chap. 7).

Unfortunately, the experimental work with livestock has not been as valuable as that done on the grasslands. This was mainly so because the livestock policy at the Farm was more and more governed by the experimental requirement of the grassland trials. However, in the earlier stages it was found that more reliable results were obtained from the home-bred stores cattle than from purchased stores.

Experimental trials in horticulture were initiated in 1900 and the work so far accomplished includes apple culture and research on vegetables (Chap. 9).

It was again Somerville who planned trials in forestry in 1897 to 1898 over an area of seven and a half acres. In 1902, an arboretum was also established (Chap. 10).

Considerable efforts seem to have been made to maintain complete meteorological data and their possible correlation with crop-yields over a period of more than 60 years (Chap. 11).

Good husbandry is linked with the Cockle Park work in two ways: (a) "Application of results of various trials to the factual farming of Cockle Park"; and (b) by the achievements at the Park over the past 50 years (Chap. 12).

A comprehensive bibliography and an index are also provided.

The studies conducted at Cockle Park are of great importance and the results of various trials can be profitably utilized by all those interested in agriculture. It shows how the efforts of scientists and administrators can bear useful results. The advances made in grassland research are commendable and stress their importance in modern agriculture. Cockle Park is bound to provide great inspiration to young agriculturists and indicate the usefulness of such farms in extending the rigid laws of science to the farmer.—P. Kachroo

Essentials of Biological and Medical Physics by Stacy, R. W., Williams, D. T., Worden, R. E. and McMorris, R. O. McGraw-Hill Book Company, Inc., New York, 1960. Pp. i-xiv, 1-586, price not indicated.

Essentials of Biological and Medical Physics provides material for fundamental training in physics, and for the first time gives a compilation of the widely scattered knowledge of biophysics. The book is divided into 11 parts and 43 chapters. The

authors discuss the fundamental concepts of biophysics in Part I. They define biophysics as being in a boundary region between physics and biology and also that it applies physics to the description of biological phenomena. They discuss the system theory and isolation of various forces to which it is subjected. Methodical analyses of these systems are separately described. This is followed by a lucid description of the various types of instruments, with particular reference to their nature and application. Under components of biophysical systems are discussed the living cell and the various tissues composed of it. Part II is confined to a discussion of the mechanical and biophysical systems. The authors state that elasticity, viscosity and surface energies of cell substances are the three important mechanical properties of cell materials. Each of these properties is discussed and suitably illustrated. The elasticity-breaking strength of bones is taken next and various forces working on them are discussed.

The mechanical properties of soft elastic tissues are discussed with respect to the theory of elastomeric elasticity (and its experimental verification), the thermal behaviour of tissue on extension an account of stress, strain diagrams of living tissues, followed by an exhaustive account of tissues as relaxing and creeping-materials. This includes short notes on dynamic behaviour of materials, viscoelastic behaviour of living materials, and nature of living relaxing systems. The biophysics of muscles includes techniques in the study of muscles, their physical behaviour, comparison of muscles as an engine and its contraction at the molecular level as also the behaviour of muscle models.

Next, the authors discuss mechanical engineering of the human body with particular reference to the movement and working of the various muscles. The mechanical aspects of musculoskeletal engineering are shortly discussed with respect to muscular disorders and conditions involving skeletal malfunction. It is followed by a consideration of the response of the living tissue to *G-forces* of the type of gravitation, and its effects on the human body.

The heat and thermodynamics in life are dealt with in Part III. It discusses the living things as thermodynamic systems, the thermal relations of the human body with its environment, the thermal exposures encountered by man and the effects thereof, and application of heat in therapy.

Part IV deals with bioacoustics. It describes acoustical phenomena of biophysical interest, the biological system under forced vibration, the biological effects of ultrasomics and their clinical application, as well as their use in locating brain tumours. The account of biophysics of the detection of sound includes a discussion on the sensitiveness, sound conduction and various aspects of the ear and transmission of sound to the nervous system, including descriptions of the audiometer and hearing aids.

The biophysical study involving light forms the basis of Part V. This is restricted to a discussion of the biological effects, both useful and harmful, on life; the therapeutic utility of light, the clinical use of and application of ultraviolet therapy. The biophysics of the individual process includes a discussion on visual processes, cone vision and colour vision. This is followed by geometric optics and vision which gives an exhaustive account of the eye as an optical instrument. The physical basis of microscopy is confined mainly to a study of the various lengths and kinds of optical microscopes and

the electronic microscope. The optical activity of biological material is also discussed. The physical nature of the animal light is dealt with at the end of this part and the mechanism of biological luminescence and the efficiency of light production by animals are also discussed.

Part VI deals with gas physics in biology. The physics of external respiration and gas biophysics at high altitude flight are discussed in this part. The fluid flow systems in biology constitute Part VII. The general concept of viscosity and the viscous behaviour of blood *in vitro*, the flow of blood in living animals, hydrostatistics of body and energy of blood are discussed. The electrical systems in biology form Part VIII and are restricted to an account of the electrical properties of the tissue and the cells, their resistance, electrical impedence of the whole body, and the physical basis for bioelectrical potentials including genesis of resting potentials, etc., is discussed, the cell responses to tissue excitation and the potentials at the surface of the animal body, the effects of electricity on animals and electrodiagnosis, electro-therapy and diathermy are also discussed.

Part IX deals with nuclear physics in biology and discusses elements, radioactivity neutrons and X-rays. The interaction of ionizing radiations with matter and measurement of radioactivity; the biological effects of ionizing radiations to which animals are subjected, damage to specific biological systems, radiation tolerance levels and its effect on biological material in general; biological and medical applications of nuclear radiations are also discussed.

Part X discusses some aspects of theoretical biophysics.

The book is profusely illustrated and each chapter is concluded with a number of references. In some chapters subject references are also listed. There is an appendix of tables which should be of great use both to students and specialists, and an exhaustive index. Dr. Glasser rightly remarks (in the introduction to the book) that "it is destined to become a milestone in the history of biophysics and medical physics", that the entire field of biophysics has been covered in a comprehensive and compact manner, and that it is expected to prove highly useful to students of the subject as well as to the biologist and the physicist. The production values of the book are very good.

—P. Kachroo

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